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UNIT REQUIREMENTS FOR PRODUCING MARKET MILK IN DELAWARE.

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CHARACTER AND SCOPE OF THE WORK.

What does it cost to produce milk? Dairymen everywhere want an answer to this important question. To supply accurate information along this line the United States Department of Agriculture, through the Dairy Division of the Bureau of Animal Industry, began a series of field studies in 1915, which have been completed and bulletins published on the requirements for producing milk in typical market-milk sections of North Carolina, Indiana, Vermont, Washington, Louisiana, and Nebraska.

The project with which this bulletin deals was organized in Delaware in June, 1919. The milk from this section is sold as market milk in Philadelphia and Wilmington. The cost of producing milk depends in part on the sanitary conditions and equipment in the dairy and the care exercised in maintaining cleanliness and in keeping milk

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at low temperatures Cost of production thus varies somewhat, according to the grade of milk produced, and in view of that fact no farms producing either very high or very low grades were included in the work.

The herds and farms were typical of dairy farms in the section studied. The figures reported show the relation of the various factors involved in producing milk in this section and probably approximate the requirements of similar districts, but they do not apply to dairying in localities where other conditions and methods of management prevail. Here dairying is not the chief industry, for grain growing is the most common type of farming. A typical farm of 400 acres would have from 100 to 130 acres of wheat, from 60 to 100 acres of field corn, and possibly 3 to 8 acres of potatoes. This acreage with the wood lot and some waste land leaves only a limited space devoted to pasture and to the growing of crops for livestock.

METHODS USED IN OBTAINING DATA.

The figures are actual records obtained by regular monthly 24-hour visits to 15 farms during the first year, and 16 farms the second year. The work was continued for the second year on 13 of the 15 farms visited the first year.

On his regular monthly inspection tour the field agent arrived at the first farm of a group in time to observe the first labor operations connected with the evening chores. With watch in hand he noted and recorded the exact time each operation about the dairy was begun and ended. He verified the records of feeds that were being fed on the inspection day, recording the kind, quantity, cost, and description of each. The quantity of milk sold each month and the receipts therefrom were noted. In addition, the whole milk used by the proprietor and his help and fed to calves which were being raised was measured or weighed and used as a basis for determining the quantity kept on the farm during the month. Accurate data on the calves and first-hand information on methods of handling manure were also collected.

Each dairyman kept an itemized account of expenses which were incurred between the monthly visits, such as the purchase or sale of cows and hides, outside bull service, and other miscellaneous information relative to the herd. These items were recorded by the field agent.

When the work about the dairy had been completed for the day at the first farm and all information relative to the dairy business recorded, the field agent drove to the next farm in time to observe the labor operations connected with the evening chores. This program was followed each week, so that each farm under observation

was visited for a working day every 30 days throughout the one or two years it was under observation.

By obtaining records on every dairy regularly each month the influence of unusual circumstances at the time of any particular visit was lessened, and by using the records of all the herds for each month complete data for each month, season, and year were obtained. Data were obtained for two entire years in order to compare one year with the other in the same section and to increase the amount of data for study.

SEASONAL INFLUENCE OF WINTER AND SUMMER ON COST FACTORS.

Since the winter and summer seasons have a marked influence on the principal factors entering into the cost of producing milk, the results have been computed separately for those periods. The months from November to April, inclusive, represent the winter season and from May to October, inclusive, the summer season.

The various tables found in this bulletin are based upon the figures obtained during the two years of the study, and the weighted average of the 2-year records was used whenever it would more accurately express the result. The weighted average was obtained by giving to each item a weight proportionate to its importance in comparison with the other items making up the average.

DESCRIPTION OF HERDS.

During the first year, records were obtained on 15 herds. The size of the herds was determined by the number of cows kept in the herd for 12 "cow-months." "Cow-month" is a term used to express the record of one cow in the herd for one month. Computed on this basis, the first year's study included 248.7 cows, with an average yearly production of 5,556 pounds of milk averaging 3.6 per cent butterfat. The second year's study included 281.6 cows in 16 herds, with an average yearly production of 5,326 pounds of milk and an average butterfat test of 3.6. The Holstein breed in both grade and purebred animals far outnumbered all the other breeds combined. Some of the herds had a few Guernseys and Jerseys.

REQUIREMENTS FOR PRODUCING MILK.

Wherever possible, the requirements have been expressed in terms of pounds of feed and hours of labor so as to eliminate as much as possible the effect of fluctuating prices.

TABLE 1.—*Units required, except charge for management, for producing 100 pounds of milk in winter and in summer.*

Item.	Winter.		Summary of two winters.	Summer.		Summary of two summers.
	1919–20.	1920–21.		1919–20.[1]	1920–21.[2]	
Feed:						
Purchased concentrates ... pounds	36.2	38.2	37.2	18.4	9.7	13.6
Home-grown grains ... do	17.5	15.5	16.5	3.5	.6	1.9
Total concentrates ... do	53.7	53.7	**53.7**	21.9	10.3	**15.5**
Hauling and grinding grain	$0.01	$0.01	$0.01	$0.003	.....	**$0.002**
Noncommercial roughage ... pounds	81.4	95.7	88.3	4.1	3.9	4.0
Commercial carbohydrate hay ... do	13.3	28.8	20.8	2.3	1.0	1.6
Commercial legume hay ... do	5.9	4.2	5.1	1.8	.2	.9
Total dry roughage ... do	100.6	128.7	**114.2**	8.2	5.1	**6.5**
Silage and other succulent roughage ... pounds	76.2	106.6	**91.0**	12.5	5.1	**10.3**
Bedding ... do	17.4	18.4	**17.9**	4.1	2.8	**3.4**
Pasture	$0.04	$0.09	**$0.06**	$0.47	$0.49	**$0.48**
Labor:						
Human ... hours	2.6	2.7	**2.6**	2.7	2.4	**2.5**
Horse ... do	.5	.5	**.5**	.5	.3	**.4**
Other costs:						
Building charges	$0.23	$0.28	$0.25	$0.26	$0.23	$0.25
Equipment charges and dairy supplies	.09	.12	.10	.10	.10	.10
Herd charges: Taxes, insurance, veterinary service, medicines, and disinfectants	.10	.07	.08	.11	.06	.08
Interest on cow investment	.12	.23	.17	.13	.19	.16
Cost of keeping bull	.14	.19	.16	.12	.15	.14
Motor-truck charge	.03	.02	.03	.03	.02	.02
Cash hauling of milk	.....	.....	.....	.003	.....	.....
Total other costs, except depreciation on cows	.71	.91	.79	.753	.75	.75
Depreciation on cows	.12	.36	.24	.14	.30	.23
Total other costs	$0.83	$1.27	**$1.03**	$0.893	$1.05	**$0.98**

[1] The summer season of 1919–20 consisted of June, July, August, September, and October of 1919 and May of 1920.
[2] June, July, August, September, and October of 1920 and May of 1921.
NOTE.—The summaries of the unit requirements are printed in bold-faced type for convenient reference.

During the winter a large quantity of grain was fed for each 100 pounds of milk produced. The decreased quantity of grain fed during the second summer as compared with the first summer should be noted.

TABLE 2.—*Number of cows, average production, and requirements for keeping a cow during each season and for the entire year, except charge for management.*

Item.	Winter.	Summer.	Entire year.
Number of cows	520.0	540.5	530.3
Average production per cow ... pounds	2,725	2,714	5,439
Feed:			
Purchased concentrates ... do	1,014	368	1,382
Home-grown grains ... do	451	52	503
Total concentrates ... do	1,465	420	1,885
Hauling and grinding grain	$0.30	$0.04	$0.34
Noncommercial roughage ... pounds	2,407	108	2,515
Commercial carbohydrate hay ... do	568	42	610
Commercial legume hay ... do	139	25	164
Total dry roughage ... do	3,114	175	3,289

TABLE 2.—*Number of cows, average production, etc.*—Continued.

Item.	Winter.	Summer.	Entire year.
Feed—Continued.			
Silage and other succulent roughage ..... pounds	2,479	281	2,760
Bedding ..... do	486	92	578
Pasture	$1.75	$12.93	$14.68
Labor:			
Human ..... hours	71.9	68.2	140.1
Horse ..... do	13.1	10.7	23.8
Other costs:			
Building charges	$6.93	$6.67	$13.60
Equipment charges and dairy supplies	2.73	2.63	5.36
Herd charges: Taxes, insurance, veterinary service, medicines, and disinfectants	2.29	2.20	4.49
Interest on cow investment	4.72	4.54	9.26
Cost of keeping bull	4.45	3.76	8.21
Motor-truck charge	.72	.75	1.47
Cash hauling of milk	.....	.04	.04
Total of other costs except depreciation on cows	21.84	20.59	42.34
Depreciation on cows	6.42	6.17	12.59
Total of other costs	28.26	26.76	55.02

CREDIT FOR CALVES.

The large credit of 95 calves for each 100 cows in the herds during the first year was greater than one would ordinarily expect. It was due to a considerable number of cows being sold out of the herds a few months after freshening.

During the second year calves brought lower prices, thus reducing the income from that source.

TABLE 3.—*Credits by years and by seasons for calves produced.*

Item.	Credit by years.		Credit by seasons.	
	1919–20.	1920–21.	Both winters.	Both summers.
Number of calves	236	247	272	211
Total value of calves	$3,929.96	$3,275.90	$3,828.76	$3,377.10
Average value of calves	16.65	13.26	[1] 14.08	[1] 16.01
Calves per cow	.95	.88	1.52	1.39
Credit per cow	$15.80	$11.63	[1] $7.36	$6.25
Credit per 100 pounds of milk	0.017 of 1 calf.	0.016 of 1 calf.	0.019 of 1 calf.	0.014 of 1 calf.

[1] These figures are the weighted averages for the respective seasons.

CREDIT FOR MANURE.

Three factors were considered in determining the credit for manure: (1) The proportion of fertilizing constituents in the feed which was returned in the manure, as taken from standard tables; (2) the per cent of manure voided in the barn; and (3) the per cent of the fertilizing constituents saved in storing and handling.

A cow digesting her feed utilizes on the average approximately 25 per cent of the nitrogen, 30 per cent of the phosphorus, and 15 per cent of the potash contained in the feed. It is evident, then, that 75 per cent of the nitrogen, 70 per cent of the phosphorus, and 85 per cent of the potash are voided in the urine or in the solid portion of the manure.

Dairymen who wish to reduce their net cost of production should remember two important facts in regard to manure: First, that a large proportion of the fertility value represented by the purchase price of the feeds may be recovered by saving all the liquid and solid portions of the manure; and, second, that the urine is more valuable than the solid manure as a source of that high-priced plant food, nitrogen. One of the big losses in liquid manure on many farms is due to leaky floors in the stable.

TABLE 4.—*Credits for manure and fertilizing constituents during the two winters and the two summers.*

Item.	Winter.			Summer.		
	1919–20	1920–21	Average.[1]	1919–20[2]	1920–21[2]	Average.[1]
Total manure saved.....tons..	656.0	[3] 515.7	585.9	153.8	81.4	117.6
Manure per cow.....pounds..	5,269	3,806	4,506	1,238	558	870
Manure credited per 100 pounds of milk.....do....	180	150	165	47	20	32
	Winter average.			Summer average.		
	Nitrogen.	Phosphoric acid.	Potash.	Nitrogen.	Phosphoric acid.	Potash.
Fertilizing constituents in manure.....pounds..	6,035	2,226	4,922	1,211	447	988
Credit per cow.....do....	23.2	8.6	18.9	4.5	1.7	3.7

[1] The averages are weighted.
[2] See notes to Table 1.
[3] Not as large a proportion of the manure voided the second year was saved.

According to Table 4, an average of 4,506 pounds, or slightly over 2.2 tons, of manure was saved per cow during the winter six months. A 1,000-pound cow voids about 6½ tons of manure in six months. The difference between these two amounts shows the quantity which was voided in the yards or was lost in storing or handling. This was due to the fact that much of the manure, especially the liquid portion, was lost through the floors in the barns or allowed to leach away when stored in piles exposed to the weather. Only the manure which was or could have been saved by using reasonable care with the equipment available was credited to the cows. The quantity of manure dropped was approximated by keeping a record of the time the cows were actually in the barn.

A ton of average manure saved on the farms studied, according to the methods used for determining it, was estimated to contain the following fertilizing constituents:

	Pounds.
Nitrogen	10.3
Phosphoric acid	3.8
Potash	8.4

When the nitrogen in commercial fertilizers was worth 18 cents, phosphoric acid 5 cents, and potash 6 cents per pound, the fertilizing value of these ingredients in a ton of manure would have been $2.55.

REQUIREMENTS FOR KEEPING A BULL.

On most of the farms the bulls were fed a comparatively small quantity of grain. In summer they were generally allowed to run on pasture with the cows.

The large proportion of noncommercial roughage used, which consisted chiefly of corn fodder and stover, shows that the herd sires were fed as cheaply as possible. The yearly cost of keeping the bull was not low, however, due to the size of each of the items under "Other costs."

TABLE 5.—*Requirements for keeping a bull by seasons, based on averages obtained from the equivalent of 31 bulls.*

Item.	Winter.	Summer.	Entire year.
Feed:			
Purchased concentrates ... pounds	408	289	697
Home-grown grain ... do	210	72	282
Total concentrates ... do	618	361	979
Noncommercial roughage ... do	2,712	123	2,835
Commercial carbohydrate hay ... do	474	554	1,028
Commercial legume hay ... do	172	181	353
Total dry roughage ... do	3,358	858	4,216
Succulent roughage ... do	720	137	857
Bedding ... do	20	16	36
Pasture	$1.08	$10.02	$11.10
Human labor ... hours	12.1	9.1	21.2
Other costs:			
Insurance and interest on bull investment	$11.31	$11.46	$22.77
Bull's share of buildings	6.99	7.07	14.06
Depreciation	15.71	15.92	31.63
Total other costs	34.01	34.45	68.46
Credit for outside bull service		2.43	2.43
Total other costs less outside bull service	34.01	32.02	66.03

FACTORS INVOLVED IN THE PRODUCTION OF MILK.

FEED.

Concentrates, in the meaning of this study, are grains and their by-products prepared for feeding.

Home-grown grains are concentrates grown on the farm or in the locality where fed.

Dry roughage includes various hays and other bulky feeds. Dry roughage is divided into the three following classes: *Noncommercial dry roughage* applies to coarse feeds, such as corn fodder and other roughages for which price quotations are not given in the trade papers. Hay or other dry roughage so foul with weeds or so damaged in curing as not to be readily salable was also classified under this heading. *Commercial legume hay* includes alfalfa, clover, and other marketable legume hays, when pure, or when so slightly mixed with grasses as not materially to affect the protein content. *Commercial carbohydrate hay* refers to all marketable hays except those classified as legume hay.

Succulent roughage consists of corn silage, potatoes, beets, and soiling crops.

The quantities of the various feeds used were obtained from actual weighings made by the field agent on his regular monthly visit to each farm.

Purchased concentrates were charged at the prices paid. The home-grown grains were given the farm price. Charges for hauling and grinding home-grown grain were not included in the price but were recorded separately. The value of silage was based upon the value of the grain and roughage in it, less the difference between the cost of harvesting the corn and the cost of putting it into the silo.

PASTURE.

The rent for permanent pasture was determined by adding to the interest on the unimproved value of the land the cost of maintaining fences and incidentals, such as seeding. Where stubble land was pastured after the grain had been harvested or when meadows were grazed after the hay had been removed, a charge was made equal to the rent value of permanent pasture for the month which best represented the quantity of feed obtained from the stubble or meadow.

Some of the herds had the run of cheap bottom-land pasture, worth about one-fifth the value of cultivated land. Two other herds were short of pasture practically all the time during the two years of study. This latter fact materially increased the cost of production.

LABOR.

Throughout this 2-year study the cost of management has not been included in the charge for labor, because no satisfactory basis has been found upon which to make this charge. The physical labor of the manager was charged up at the same rate per hour as he would have had to pay if he had hired a man of equal skill to take his place.

TABLE 6.—*Per cent of labor performed and hours per 100 pounds of milk for each class of help.*

Class of labor.	Winter.				Summer.			
	Distribution of work performed.			Labor for 100 pounds of milk.	Distribution of work performed.			Labor for 100 pounds of milk.
	1919–20	1920–21	Average.	Average.	1919–20[1]	1920–21[1]	Average.	Average.
	Per cent.	*Per cent.*	*Per cent.*	*Hours.*	*Per cent.*	*Per cent.*	*Per cent.*	*Hours.*
Managers	28.1	28.4	28.2	0.74	25.2	28.5	26.9	0.67
Hired men	68.3	67.7	68.0	1.80	67.2	60.6	63.7	1.60
Total man labor	96.4	96.1	96.2	2.54	92.4	89.1	90.6	2.27
Women	1.2	1.5	1.4	.04	1.8	1.4	1.6	.04
Boys and girls	2.4	2.4	2.4	.06	5.8	9.5	7.8	.20
Total	100.0	100.0	100.0	2.64	100.0	100.0	100.0	2.51

[1] See notes to Table 1.

The production of market milk in this section is mostly a man's job, as is shown in Table 6. In winter men performed 96.2 per cent of the work about the dairy. But in summer, especially during the vacation months, boys and girls performed more of the work, thus reducing the proportion of man labor for the summer season to 90.6 per cent.

Work about the dairy is divided into three groups—production, handling, and hauling to the shipping platform. Production includes feeding, milking, and the general care of the herd. Handling comprises such items as washing utensils, cooling the milk, and getting it ready for hauling. In this section part of the milk was shipped by train and part transported by large motor trucks to the city.

TABLE 7.—*Human labor used in producing, handling, and hauling 100 pounds of milk to the shipping platform.*

Kind of work.	Winter.				Two winters.		Summer.				Two summers.	
	1919–20.		1920–21.				1919–20.[1]		1920–21.[1]			
	Hours.	*Per ct.*	*Hours.*	*Per ct.*	*Hours.*	*Per ct.*	*Hours.*	*Per ct.*	*Hours.*	*Per ct.*	*Hours.*	*Per ct.*
Production	2.2	84.7	2.2	82.0	2.2	83.3	2.1	76.0	1.9	79.0	2.0	77.6
Handling	.1	4.6	.2	5.5	.1	5.1	.2	8.4	.2	7.5	.2	7.9
Hauling	.3	10.7	.3	12.5	.3	11.6	.4	15.6	.3	13.5	.3	14.5
Total	2.6	100.0	2.7	100.0	2.6	100.0	2.7	100.0	2.4	100.0	2.5	100.0

[1] See notes to Table 1.

OTHER COSTS.

Under the heading of "Other costs" are grouped miscellaneous charges, such as interest, taxes, insurance, and depreciation on the herd, buildings, and equipment; also the cost of keeping the bull and similar items.

In Delaware the farm property is assessed for taxation by four men who visit each farm. These men place a separate market value on the different grades of raw land, such as swamp, tillable, etc. The value of the buildings is appraised, as is also the market value of the livestock. Since values are not placed on the separate buildings and on cows individually by these assessors, the field man had another appraiser visit each herd and value each building and cow separately, using the total figures of the assessors as a basis.

BUILDINGS.

The first column of Table 8 shows that the 2-year average investment in dairy buildings, including silos, was $148.14 per cow. The investment in buildings the first year was $111.07 per cow. The higher investment for the 2-year average was due to one dairyman constructing a barn and two tile silos which cost $25,500. The 2-year average investment in buildings, not including the large barn and silos, would have been $100.05 per cow. This investment is also higher than it would have been had not a number of other barns and silos been erected during recent years when prices were high; also a number of tile silos were erected which had large initial costs.

The depreciation of the buildings was based upon their remaining years of usefulness. Insurance charges were obtained from the insurance agents. The cost for upkeep and repairs was obtained by keeping an actual record of expenditures during the year.

The footing of the first column shows that the total of the costs against buildings amounted to 9.7 per cent of the capital invested in buildings. The other footings show corresponding percentage relationships.

TABLE 8.—*Per cent relationship between "other costs" and capital invested.*

Item.	Buildings.	Equipment.	Cattle.	Total.
Capital invested	$78,560.82	$8,566.18	$82,158.00	$169,285.00
Capital invested, per cow	148.14	16.15	154.93	319.22
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
Interest	4.9	5.3	6.0	
Depreciation	2.9	22.3	8.1	
Taxes	.9		1.3	
Insurance	.3			
Upkeep and repairs	.7	1.1		
Milking-machine repairs		.2		
Total	9.7	28.9	15.4	[1] 13.5

[1] Per cent which the expenses listed bear to total investment.

EQUIPMENT.

A monthly record of repairs and renewals of equipment was kept. The amounts spent for dairy supplies were also recorded monthly and amounted during the year to 69 cents per cow.

CATTLE.

The cows had an average inventory value of $154.93. Purebred cows were inventoried at fair prices for grade cows of similar producing ability, and the calves dropped by purebred cows were inventoried at corresponding grade values. Inventories were taken at the beginning and end of each year. The depreciation or appreciation in value of cows was obtained in the following manner: The values of heifers freshening or cows purchased during the year were added to the first inventory and the values of cows or hides sold during the year were added to the inventory at the end of the year. The difference between the two inventories, after these additions, represented the depreciation or appreciation on the herd for the year.

The feed, labor, and "other costs" of keeping the herd sires were kept separate, so that they would be available for study.

Interest was charged at 6 per cent, the prevailing rate in the section. Records were kept of the actual amounts of money spent during the year for veterinary services, medicines, and disinfectants. These expenditures amounted to 87 cents per cow per year.

PERCENTAGE COMPARISON OF FACTORS INVOLVED IN MILK PRODUCTION.

How much more did it cost to produce milk in winter than in summer? What caused the variation in cost? Did the credit for calves and manure equal the debit for either labor or "other costs"? Table 9 answers these questions for the section studied.

TABLE 9.—*Per cent of the total costs represented by feed, labor, and "other costs," by seasons.*

Item.	Winter.	Summer.	Entire year.
	Per cent.	*Per cent.*	*Per cent.*
Feed and bedding cost	35.9	8.9	44.8
Pasture	.9	7.3	8.2
Feed, bedding, and pasture cost	36.8	16.2	53.0
Labor cost	8.6	8.1	16.7
Other costs, except herd inventory variation	11.8	11.5	23.3
Total cost except herd inventory variation	57.2	35.8	93.0
Depreciation on herd	3.5	3.5	7.0
Total cost of production	60.7	39.3	100.0
Credits:			
Calves	4.0	3.5	7.5
Manure	4.7	1.0	5.7
Total credits	8.7	4.5	13.2

An examination of the first two columns of Table 9 shows that the decrease in the cost of feed in summer was the principal cause of the difference in cost between winter and summer.

The credits for calves and manure for the year equal 13.2 per cent of the total cost of production, whereas labor amounted to 16.7 per

cent of the total cost. "Other costs," including depreciation on the herds, amounted to 30.3 per cent. This shows that calves and manure failed by a small margin to equal the cost of labor and by a wide margin to balance the "other costs," including depreciation on the herds.

AVERAGE COMPARED WITH BULK-LINE COSTS.

If the net cost of producing milk on various farms is tabulated in an ascending scale, together with the percentage of the whole quantity of milk produced at these separate costs, one or possibly more points will be shown at or below which a large proportion of the milk is produced. The point or line of demarcation selected is called the "bulk" line. It is usually placed where it will include between 80 and 90 per cent of the volume of milk produced.

TABLE 10.—*Net cost, quantity, and per cent of milk produced by each herd during two winters and two summers.*

Winter, 1919–20.					Winter, 1920–21.				
Herd No.	Cost per 100 pounds.	Milk produced.			Herd No.	Cost per 100 pounds.	Milk produced.		
		Quantity.	Per cent of total.	Cumulative per cent.			Quantity.	Per cent of total.	Cumulative per cent.
		Pounds.	*Per cent.*	*Per cent.*			*Pounds.*	*Per cent.*	*Per cent.*
608	$2.62	87,053	12.0	12.0	617	$2.10	36,640	5.3	5.3
605	2.73	33,431	4.6	16.6	618	2.49	44,824	6.5	11.8
602	2.94	105,963	14.6	31.2	607	2.62	11,039	1.6	13.4
606	2.99	53,315	7.3	38.5	602	2.98	84,343	12.3	25.7
603	3.03	82,615	11.4	49.9		[2] 3.02			
612	3.07	34,912	4.8	54.7	606	3.05	69,622	10.1	35.8
	[1] 3.36				619	3.10	31,203	4.5	40.3
	[2] 3.43				613	3.25	32,194	4.7	45.0
616	3.53	42,974	5.9	60.6	610	3.41	50,153	7.3	52.3
610	3.53	48,090	6.6	67.2	609	3.43	35,172	5.1	57.4
614	3.77	45,865	6.3	73.5	611	3.44	25,010	3.6	61.0
607	3.88	21,181	2.9	76.4	608	3.55	62,016	9.0	70.0
604	3.88	60,981	8.3	84.7		[1] 3.70			
609	4.07	23,634	3.2	87.9	614	3.93	51,022	7.4	77.4
613	4.14	41,844	5.8	93.7	616	4.01	46,061	6.7	84.1
615	4.20	28,529	3.9	97.6	604	4.96	46,418	6.7	90.8
611	5.53	17,238	2.4	100.0	615	5.88	23,414	3.4	94.2
					603	7.95	40,087	5.8	100.0
Summer, 1919–20.[3]					Summer, 1920–21.[3]				
610	$1.49	39,749	6.1	6.1	617	$1.11	51,326	6.3	6.3
608	1.83	52,016	8.0	14.1	610	1.27	49,454	6.1	12.4
606	1.90	43,229	6.6	20.7	606	1.32	61,341	7.6	20.0
603	2.01	69,523	10.6	31.3	619	1.46	50,590	6.2	26.2
616	2.01	41,097	6.3	37.6	618	1.53	62,833	7.7	33.9
607	2.12	24,997	3.8	41.4	607	1.55	25,524	3.1	37.0
612	2.20	29,056	4.4	45.8	611	1.79	44,409	5.5	42.5
	[1] 2.40				602	1.92	71,591	8.8	51.3
615	2.47	36,095	5.5	51.3	609	1.95	35,066	4.3	55.6
609	2.49	22,155	3.4	54.7	616	1.99	56,484	7.0	62.6
602	2.52	91,560	14.0	68.7	613	2.03	35,940	4.4	67.0
611	2.53	28,423	4.4	73.1		[1] 2.19			
605	2.58	32,953	5.0	78.1	608	2.43	65,825	8.1	75.1
613	2.79	54,156	8.3	86.4	614	3.13	31,703	3.9	79.0
604	3.19	50,343	7.7	94.1		[2] 3.16			
	[2] 3.32				615	3.38	39,252	4.8	83.8
614	3.84	38,610	5.9	100.0	603	3.64	82,232	10.1	93.9
					604	4.18	49,475	6.1	100.0

[1] Average net cost. [2] Average income from milk. [3] See notes to Table 1.

In the scale of costs for the first winter in Table 10, the location for the bulk line on this basis is immediately following $3.88. It will be noted that 84.7 per cent of the milk was produced at $3.88, or less, per 100 pounds.

The schedule of costs for the second winter shows a sharp increase in price after 84.1 per cent of the volume of milk was produced. Thus at $4.96 only 6.7 per cent more milk was produced but at an increased cost of 95 cents per 100 pounds. A similar sharp increase also exists at $5.88, the increase in volume of milk at this cost being only 3.4 per cent and the increase in cost amounting to 92 cents.

These results emphasize two equally important facts: First, that the income from milk in winter failed by a large margin to equal the cost of production for the bulk-line supply; and, second, that there was a wide range in costs between the more efficient dairymen and the higher cost producers. Where a winter supply of milk is needed, the price must be high enough to stimulate increased production to the necessary demand.

In the dairy business, as in other industries, the net income depends upon net profit made from milk sold and upon the volume of milk sold.

MONTHLY DISTRIBUTION OF FACTORS IN MILK PRODUCTION.

How did the quantity of milk produced in summer compare with that in winter? Did the monthly income received for milk sold fluctuate fairly uniformly with the quantity sold? Did the dairymen receive the higher income during those months when it cost the most to produce milk? Table 11 gives information on these queries. Yearly figures were used as the basis for computing percentages.

TABLE 11.—*Distribution by months of milk prices, milk sold and used, feed cost, and labor required.*

Month and season.	Income per 100 pounds of milk.	Income from milk sold and used.	Milk sold and used.	Feed, pasture, and bedding cost.	Pasture and bedding cost minus manure and bedding credits.	Human labor.		Horse labor.	
						Per 100 pounds of milk.	Per cow.	Per 100 pounds of milk.	Per cow.
1919-20.		*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Hours.*	*Hours.*	*Hours.*	*Hours.*
May	$3.23	10.3	10.9	5.3	4.9	2.1	12.5	0.3	2.0
June	3.03	9.0	10.1	4.5	4.1	2.4	13.4	.4	2.2
July	3.07	6.4	7.1	4.6	4.2	3.1	12.5	.5	2.2
August	3.45	6.5	6.4	4.7	4.3	3.2	11.6	.7	2.5
September	3.73	7.2	6.5	5.6	5.6	3.1	10.9	.6	2.0
October	3.98	7.1	6.1	6.1	5.7	3.1	10.3	.4	1.2
Summer	3.36	46.5	47.1	30.8	28.4	2.7	11.8	.5	2.0
November	3.62	7.4	6.9	7.8	6.0	2.7	10.0	.3	1.1
December	3.54	8.5	8.1	11.9	10.1	2.8	12.4	.6	2.4
January	3.46	9.5	9.4	12.9	11.1	2.7	14.1	.5	2.6
February	3.36	9.3	9.4	11.9	10.1	2.5	13.2	.4	2.4
March	3.33	9.8	10.0	12.5	10.7	2.6	14.5	.6	3.4
April	3.36	9.0	9.1	12.2	10.4	2.5	12.4	.4	1.9
Winter	3.43	53.5	52.9	69.2	58.4	2.6	12.8	.5	2.3
Year	3.40	100.0	100.0	100.0	86.8	2.7	12.3	.5	2.2

TABLE 11.—*Distribution by months of milk prices, etc.*—Continued.

Month and season.	Income per 100 pounds of milk.	Income from milk sold and used.	Milk sold and used.	Feed, pasture, and bedding cost.	Pasture and bedding cost minus manure and bedding credits.	Human labor.		Horse labor.	
						Per 100 pounds of milk.	Per cow.	Per 100 pounds of milk.	Per cow.
1920-21.		*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Hours.*	*Hours.*	*Hours.*	*Hours.*
May	$2.48	8.2	10.2	5.2	5.0	2.2	12.3	.3	1.7
June	3.11	9.2	9.2	5.1	4.9	2.4	11.2	.4	2.0
July	2.87	9.5	10.2	4.2	4.0	2.1	10.9	.3	1.6
August	3.38	9.4	8.6	4.7	4.5	2.6	11.5	.3	1.4
September	3.52	9.3	8.1	5.5	5.3	2.4	9.6	.4	1.6
October	3.85	9.6	7.8	5.8	5.7	2.5	10.2	.3	1.3
Summer	3.15	55.2	54.1	30.5	29.4	2.4	10.9	.3	1.6
November	3.86	9.1	7.3	9.0	7.9	2.4	9.3	.3	1.2
December	3.02	6.6	6.8	12.1	11.0	2.8	11.2	.5	2.0
January	2.86	6.6	7.0	12.7	11.6	2.9	11.7	.7	2.8
February	2.90	6.2	6.7	11.8	10.7	3.0	11.1	.7	2.6
March	2.87	7.6	8.2	13.3	12.1	2.8	12.6	.5	2.1
April	2.74	8.7	9.9	10.6	9.4	2.2	12.0	.3	1.8
Winter	3.03	44.8	45.9	69.5	62.7	2.7	11.3	.5	2.1
Year	3.10	100.0	100.0	100.0	92.1	2.5	11.1	.4	1.8

The second column shows that 46.5 per cent of the yearly income for the first year was obtained during the summer six months. The third column shows that this income in summer was received in return for the sale of 47.1 per cent of the yearly volume of milk produced.

The fourth column indicates that this volume of milk was obtained for 30.8 per cent of the yearly gross feed cost.

In winter it took 69.2 per cent of the gross yearly feed cost to produce 52.9 per cent of the yearly volume of milk which brought in 53.5 per cent of the yearly income received from it. The conclusion drawn from these figures and from those for the second year is that income and volume of milk sold closely followed each other, but income and gross feed cost required to produce milk did not follow each other.

SUMMARY.

In this investigation the requirements for producing milk were obtained from records covering two 1-year periods. During the winter months the requirements for producing 100 pounds of milk having an average butterfat test of 3.6 per cent were: Concentrates, 53.7 pounds; hauling and grinding concentrates, $0.01; dry roughage, 114.2 pounds; silage and other succulent roughage 91 pounds; bedding, 17.9 pounds; pasture, $0.06; human labor, 2.6 hours; horse labor, 0.5 hour; total other costs except depreciation on cows, $0.79; depreciation on cows, $0.24.

During the summer months the requirements for producing 100 pounds of milk were: Concentrates 15.5 pounds, hauling and grinding concentrates $0.002; dry roughage, 6.5 pounds; silage and other succulent roughage 10.3 pounds; bedding 3.4 pounds; pasture $0.48; human labor 2.5 hours; horse labor 0.4 hour; total other costs except depreciation on cows $0.75; depreciation on cows $0.23. (See Table 1.)

The average production per cow per year was 5,439 pounds of milk and the requirements for keeping a cow one year were: Concentrates 1,885 pounds; hauling and grinding concentrates $0.34; dry roughage 3,289 pounds; silage and other succulent roughage 2,760 pounds; bedding 578 pounds; pasture $14.68, human labor 140.1 hours; horse labor 23.8 hours; total other costs except depreciation on cows $42.43; depreciation on cows $12.59. (See Table 2.)

There was a credit, per year, of 0.91 of one calf for each cow. (See Table 3.) The credit for manure per cow amounted to 5,376 pounds. (See Table 4.) It was estimated that a ton of this manure contained 10.3 pounds of nitrogen, 3.8 pounds of phosphoric acid, and 8.4 pounds of potash.

In the winter season 28.2 per cent of the work was performed by the managers, 68 per cent by hired men, 1.4 per cent by women, and 2.4 per cent by boys and girls. During the summer 26.9 per cent was performed by the managers, 63.7 per cent by hired men, 1.6 per cent by women, and 7.8 per cent by boys and girls. (See Table 6.)

In winter 83.3 per cent of the labor was expended for production, 5.1 per cent for handling, and 11.6 per cent for hauling. During the summer 77.6 per cent of the labor was expended for producing milk, 7.9 per cent in handling, and 14.5 per cent in hauling the milk. (See Table 7.)

The capital invested in buildings amounted to $148.14 per cow. The equipment investment per cow was $16.15 and the investment in the cows themselves amounted to $154.93 per cow. The annual charges for interest, depreciation, taxes, and similar items on buildings amounted to 9.7 per cent of the capital invested. The equipment expense amounted to 28.9 per cent of the investment in equipment, and the expenses against the cows themselves amounted to 15.4 per cent of the investment. The combined yearly charge for buildings, equipment, and herd was 13.5 per cent of the total capital invested in them. (See Table 8.)

Fifty-three per cent of the cost of producing milk was due to feed, bedding, and pasture; 16.7 per cent to labor, 7 per cent to depreciation on cows, and 23.3 per cent to other costs. There was a credit of 7.5 per cent for calves and 5.7 per cent for manure. (See Table 9.)

The average costs of producing milk were $3.36 and $3.70 per 100 pounds for the two winters, respectively. The costs for the two respective summers were $2.40 and $2.19 per 100 pounds. (See Table 10.) During the first winter it took 69.2 per cent of the gross yearly feed, pasture, and bedding cost to produce 52.9 per cent of the yearly volume of milk, which brought in 53.5 per cent of the yearly income received from it. (See Table 11.) These figures and those obtained for the second year show that the income and volume of milk sold followed each other closely, but that the income and gross feed cost required to produce milk varied considerably.

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KERNEL-SPOT OF THE PECAN AND ITS CAUSE.

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DISTRIBUTION AND HISTORY.

The pecan kernel-spot is found throughout the southern pecan belt, including North Carolina, South Carolina, Georgia, Florida, Alabama, Mississippi, Louisiana, and Texas. This trouble is not evenly distributed over these States, but is more prevalent in restricted localities. Its appearance is more or less sporadic; that is, it may be abundant one season and almost absent the season following.

The first published record of an investigation of pecan kernel-spot was in 1914 by Rand (*5*).[1] As set forth in this preliminary account, the fungus *Coniothyrium caryogenum* Rand was isolated from affected pecan kernels. Rand reported that by subsequent inoculation in healthy kernels with this fungus he was able to produce in a series of laboratory experiments during 1912 and 1913 typical pecan kernel-spot symptoms. Laboratory inoculations with this fungus were so largely positive that it was considered by him to be the cause of the disease.

Since Rand made no observations or investigations in the field in reference to pecan kernel-spot, he was unable to determine the time and manner in which the infection of his isolated fungus took place

[1] Serial numbers (italic) in parentheses refer to "Literature cited" at the end of this bulletin.

under natural conditions. He gave no method of possible means of control. However, he suggests in a footnote that affected nuts should be gathered and burned, in order to lessen the chances of further spread of the disease.

Turner (*6*) reports a severe outbreak of kernel-spot throughout central and southern Georgia during the season of 1916. He, as well as several growers, observed that orchards having an abundance of kernel-spot were planted to cowpeas; also that these same orchards had a severe infestation of the southern stinkbug (*Nezara viridula* L.). He at first considered this to be possibly only a coincidence.

However, Turner conducted a preliminary experiment the following season to test the possibility of an association of pecan kernel-spot with punctures of sucking insects. His work, though conducted on a small scale and apparently with no check except nuts growing upon the tree not confined with bugs, indicated very strongly that these bugs bore either a direct or an indirect causal relation to the disease. No attempt was made at that time to determine what part the fungus *Coniothyrium caryogenum* Rand played in the cause of pecan kernel-spot.

Since one of the investigators above cited conducted his work entirely in a laboratory and from a pathological standpoint and the other did field work only, and from an entomological standpoint, and the two results were in a way contradictory or, at least, not corroborative, the growers were considerably confused as to the true cause of the disease and, therefore, as to the adoption of possible remedial measures. Consequently, the writer was urged to conduct an experiment combining both field and laboratory work to definitely determine which of the above-named investigators arrived at the correct conclusion regarding the cause of pecan kernel-spot.

ECONOMIC IMPORTANCE.

It is difficult to estimate the amount of damage and the extent of the prevalence of kernel-spot, owing to the fact that the evidences of the disease are not discernible until the shells of the nuts are removed.

Pecans from planted orchards do not ordinarily go to cracking establishments, but are widely distributed in small quantities in the shells to consumers, adding greatly to the difficulty of accurately estimating the proportion of nuts affected. While the nuts in some orchards will be entirely free from the trouble, in other orchards such a large percentage of the nuts will be spotted that the crops will be unmarketable.

The most serious losses have been reported to the writer by growers in southern Georgia, northern Florida, and Texas. The trouble

was of a serious economic importance in southern Georgia in 1916 and again in 1921. Some growers in northeastern Florida reported an entire loss of their Curtis nuts in 1919 and 1920, but these same Florida growers reported the loss to be slight in 1921.

DESCRIPTION OF KERNEL-SPOT.

The spots are found only upon the kernels of the pecan nuts. Ordinarily no evidence of the trouble is apparent until the shell is removed. The writer has observed that when nuts are punctured by the Nezara before or soon after the nuts have attained their full growth small sunken places will be formed in the shucks of the nuts. (Fig. 1.)

Punctures may also be seen in the shell if an examination is made while the nut is yet green. The pecan shell is greenish white until the maturing processes start, and during this stage punctures appear as small brown spots less than 1 millimeter in diameter. These spots can be followed through the shell by shaving or scraping with a knife, and a typical spot will usually be found on the kernel immediately beneath it. These spots are not evident on the shell after the nuts have matured and developed the nut-brown color.

FIG. 1.—A pecan nut of the Curtis variety, showing indentations caused by early punctures of *Nezara viridula*.

The centers of the spots are always found upon the ridges or the edge of the pecan kernels, and never in the creases or on the inside surface of the halves of the kernel. (Fig. 2.)

In almost all typical kernel-spots one will find a small papilla, or pimplelike structure, in approximately the center of the spot. A magnified cross section of a spot through this pimplelike structure shows the epidermal cells and those cells lying immediately beneath this point as being ruptured. (Fig. 3.) Undoubtedly this small elevated place marks the point of entrance of the seta of the insect. The kernel spots are usually but not always sunken below the surface of the adjacent healthy tissues. They vary in size from 2 to 5 millimeters in diameter.

In color, the surface of the spots ranges from brown to black. Internally the affected tissues extend in approximate hemisphere beneath the surface and are frequently separated from the healthy tissues by a distinct brown layer. The internal part of the spots is almost white, pithy and porous, and apparently is not discolored or disorganized until organisms of decomposition gain admittance. The spots are decidedly bitter, but this bitter taste is not imparted to the unaffected portions of the kernel.

PRESENT INVESTIGATIONS.

The object of the series of experiments herein reported was to determine, if possible, the true cause of pecan kernel-spot and its relation, if any, to certain sucking insects and parasitic fungi.

In preparation for this work, 250 small wire cages were made of No. 16 screen wire. The wire was cut in strips and two edges were

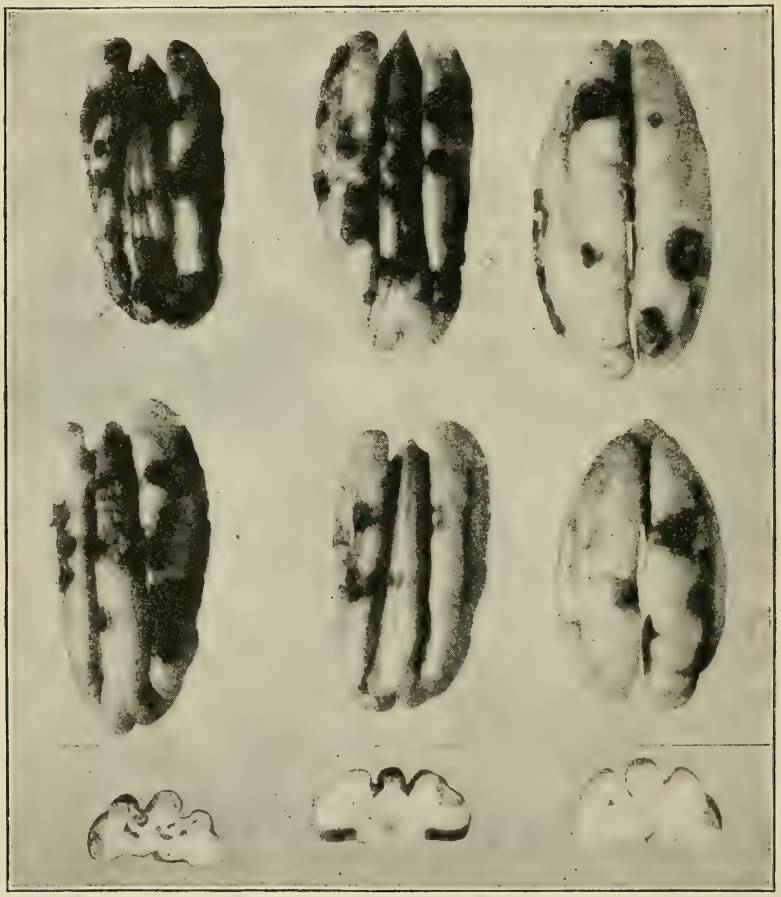

FIG. 2.—Kernel spots on Schley pecans. The upper six views show the location of the spots on the ridges and edges of the halves. The three lower views illustrate kernels cut through the spots, showing the depth and extent of the injured portions. (Enlarged about one-fourth.)

clamped and soldered together, thus forming a cylinder 6 inches long and 4 inches in diameter. Cheesecloth was sewed to each end of the cylindrical cage, with the ends open, so that the cloth at one end could be tied around the limbs just back of the cluster of nuts, thus holding the cage in a position around the cluster. (Fig. 4.) The cloth at the other end of the cage was tied during the experiment,

so that insects could be placed in the cage conveniently and also for any necessary examination of the nuts during the test.

The Schley and Curtis varieties were selected on which to conduct the experiment, owing to their apparant susceptibility to spotting.

The cages were placed in position during the last week of August and the first week of September, 1921, in the vicinity of Thomasville, Ga. From three to seven adult southern stinkbugs (*Nezara viridula* L.) [2] taken principally from cowpeas and tomatoes, were placed in each cage between September 1 and 15, except those used as checks. This species of insect (Fig. 5) was used on account of its abundance in the pecan belt of southern Georgia and also because of its fre-

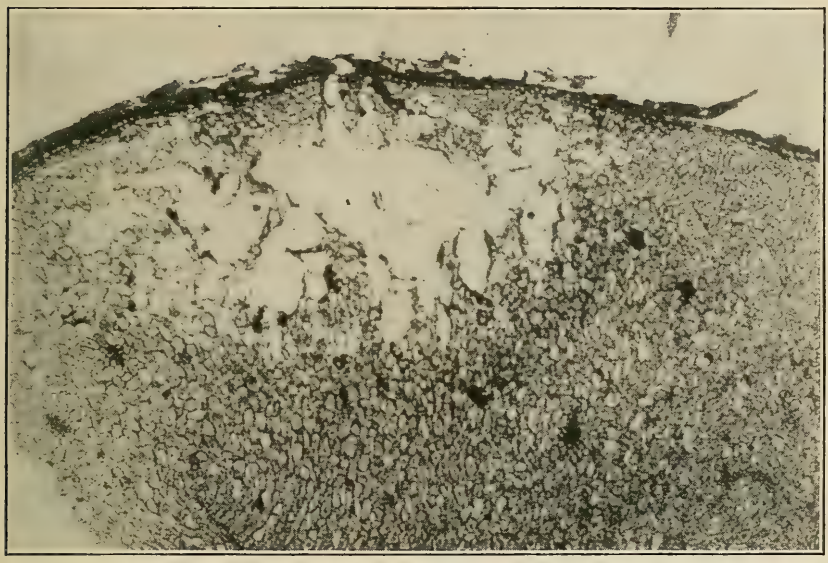

FIG. 3.—Highly magnified cross section of a kernel spot, showing the point of entrance of the insect's seta and also the greatly ruptured and collapsed cells caused by the extraction of the oil and other substances from the kernel.

quent appearance on pecan nuts. The writer has also observed a species of Leptoglossus feeding upon immature pecan nuts, but has made no attempt to determine its relation to pecan kernel-spot.

At the time the bugs were placed in the cages the nuts of the Curtis variety were immature, but had possibly attained their full size. The Schley, being an earlier variety, was showing some evidence of maturing, as indicated by a harder shell and some slight discoloration of the shuck.

Since the only object of using the insects was to determine the relationship between insect punctures and kernel-spot, no attempt

[2] Determined by W. L. McAtee, acting custodian of Hemiptera, U. S. National Museum.

was made to determine at what period the spots may appear during the development of the pecan kernel. However, the bugs are found most abundantly on pecan nuts in September and October.

The experiment required no further attention until the nuts were harvested, except to replace with live bugs those that had died. The Schley nuts were harvested on October 16 and the Curtis nuts on November 19, and the results are shown in Table 1.

TABLE 1.—*Result of experiment showing number of pecan nuts spotted when caged with and without bugs.*

Variety.	Number of nuts.	Number with kernel-spot.	Percentage of kernels spotted.
Schley, without bugs (check)	36	0	0
Schley, with bugs	145	140	95.6
Curtis, without bugs (check)	55	0	0
Curtis, with bugs	168	166	98.8

In no case did the protected nuts, or checks, show any evidence of spotting, while a very large percentage of those confined with bugs were badly affected with typical kernel spots. Many of these individual nuts had 15 to 25 spots. In fact, some nuts were so badly spotted that almost the entire kernel was discolored and partially shriveled.

An attempt was made to produce kernel-spot artificially by puncturing the nuts with sterile needles. Several punctures were made in each of 12 nuts. This work was done during the first week in September at the time when most of the bugs were placed in the other cages. The shells of the nuts had hardened to such an extent by this time that several needles were broken while attempting to force them through to the kernels. It appears to be a remarkable feat that the bugs are able to pierce through the hardening pecan shells with their delicate mouth parts. These artificially punctured nuts were examined at harvest time as to the effect the punctures had upon the kernels. While these injuries were still evident as either open holes or holes partially healed over, they in no manner resembled the spots caused by the insect punctures.

In addition to the caged nuts, an examination was made of uncaged nuts growing upon the same trees. Of 375 Schley nuts thus examined, 9 per cent were spotted. Of 82 Curtis nuts examined, 8½ per cent had kernel spots.[3]

The result of the experiment recorded above demonstrates very conclusively that punctures by the southern stinkbug (*Nezara viridula*

[3] A smaller number of uncaged Curtis nuts were examined than the writer wished, as the crop that grew upon these trees was stolen soon after it was harvested. The nuts examined were gathered under the trees as a last resort.

L.) were in these cases either directly or indirectly the cause of kernel spots, with the evidence strongly favoring a direct causal relation. The southern stinkbug is a rather omnivorous feeder. Furthermore, it will feed upon any part of the plant, but shows a decided preference for fruit and seeds. Jones (*3*), Morrill (*4*), Watson (*7*), and Drake (*2*) have cited the insect as feeding on the following plants: Tomatoes, okra, mesquite, cowpeas, beans, most Cruciferæ, cotton, citrus, peach, grape, rattlebox, etc.

Turner reports that the southern stinkbug appears to attack cowpeas when these are present in preference to all other plants, either cultivated or wild. The writer and many growers have observed that the greatest prevalence of kernel-spot over large areas is found in or near orchards where cowpeas are growing.

It is a common practice of the pecan growers throughout the southern United States to plant cowpeas between the tree rows to be used either as hay or plowed under as a cover crop. When the hay is harvested or the pea vines die down naturally the bugs, if present, will migrate to the pecan nuts, often in great numbers.

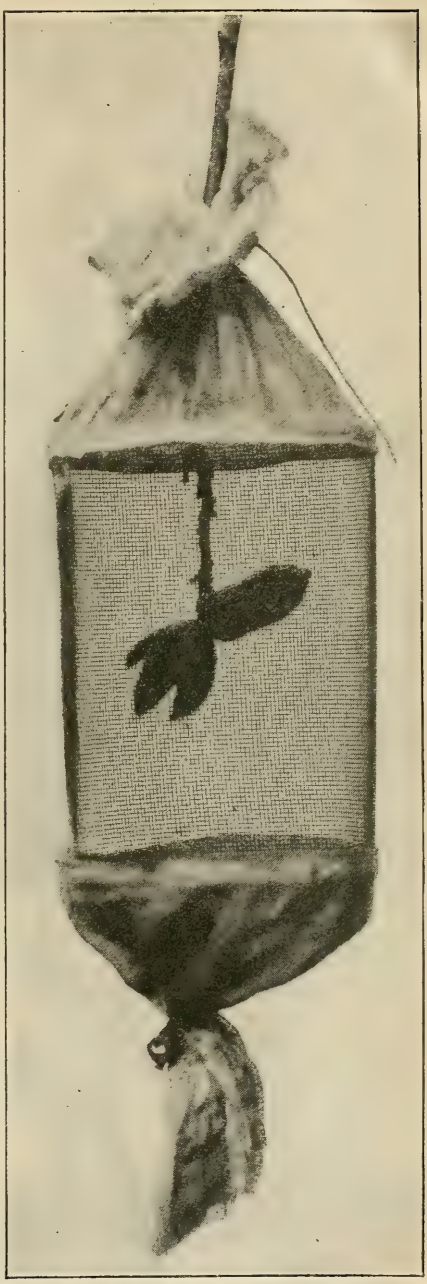

Fig. 4.—Type of cage used for confining insects with nuts.

Frequently kernel-spot will be found in great abundance on nuts that have grown in close proximity to gardens where tomatoes, okra, or other host plants are present. This is especially noticeable in orchards where some crop other than cowpeas has been planted.

SUPPLEMENTARY EXPERIMENT.

On September 15, 1921, 12 clusters of Curtis nuts were brought into the laboratory and placed in lantern-globe cages. Short stems were left on the clusters which were inserted in bottles containing water. Each cage had a strip of cheesecloth tied over its top.

From five to seven specimens of adult southern stinkbugs were placed in each of six of these cages. The other six clusters were reserved as checks, but were subjected to the same conditions, except that no bugs were confined with them.

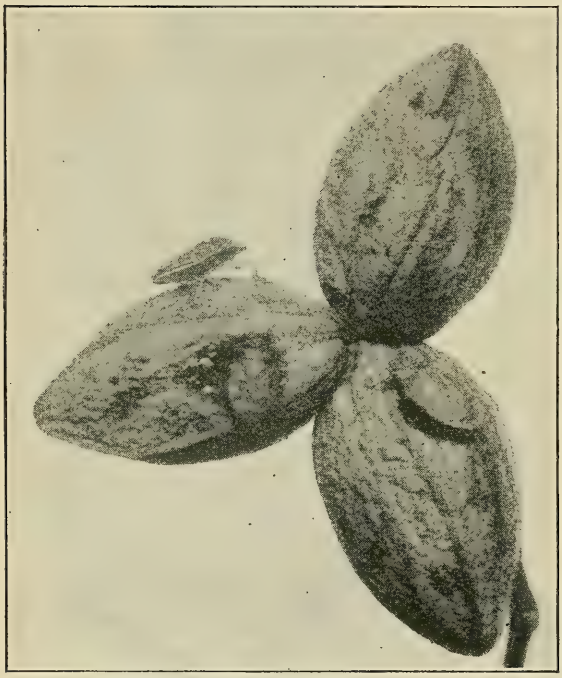

FIG. 5.—Southern stinkbugs (*Nezara viridula*) on pecan nuts of the Curtis variety. (Natural size.)

On September 18, or approximately 65 hours later, all the nuts were opened and examined. Of the 17 nuts confined with bugs, each had from 1 to 12 typical kernel spots. Of the checks, numbering 15, not the slightest evidence of kernel-spot was found on any. Cultures were made on beef agar from 10 spotted nuts of the first series. No growth of any kind was produced from these cultures.

This test alone would seem to prove that pecan kernel-spot is caused directly by the stinkbugs feeding upon the kernels or by injecting toxic substances into the tissues. It also indicates very strongly that the Nezara bugs do not regularly transmit parasitic microorganisms to the pecan kernels with their piercing mouth parts.

LABORATORY CULTURES OF KERNEL-SPOT.

Owing to the porous structure of the kernel-spots and their tendency to quickly absorb liquids, the method of soaking diseased plant tissues in a solution of mercuric chlorid in preparation for making cultures was found to be impracticable. The following method was used, giving very satisfactory results:

The surface of the kernels was wiped with absorbent cotton saturated with a 1 to 1,000 solution of mercuric chlorid. Then with a flamed scalpel the top of the spot was cut off. A section of the remaining spot with its adjacent healthy tissues was removed with the same scalpel. This was immediately transferred with a sterile needle to a Petri dish containing beef or corn-meal agar.

This method of technic eliminated the danger of killing by the absorption of mercuric chlorid any parasite or saprophyte that might happen to be in the affected tissues, and at the same time it reduced the chances of outside infection to a minimum. By employment of the above method numerous Petri dish cultures were made, in order to study the flora of the diseased spots.

The use of kernels having several spots whose internal structures were discolored very generally resulted in producing, in cultures, colonies of fungi and bacteria. This was to be expected, since several forms of saprophytic fungi and bacteria readily obtain entrance to plant tissues which have died from any cause. This is especially true of tissues which have died from mechanical injury, since they are not already inhabited with microorganisms. Eight forms of fungi and three of bacteria were quite constant, but no single one predominated except a bacterial form with a light-yellow color. This is possibly the same form referred to by Rand in his investigation previously cited.

Out of 58 spots taken from Curtis nuts that had been confined in cages with several specimens of *Nezara viridula* for a period of approximately two months, 35 produced colonies of bacteria, 19 grew fungi, and 4 remained sterile. It should be recorded here that the kernels of these nuts were so severely injured by the constant feeding of the bugs over an extended period that many blackened and internally discolored sunken spots resulted. The kernels were all dwarfed and shrunken, and the shucks of none of them opened normally. The check nuts and also uncaged nuts on the same trees were well filled, and their shucks opened at the normal time for the Curtis variety.

Cultures were made of 65 spots taken from moderately diseased Curtis nuts. Colonies of bacteria were formed in 28, 9 produced fungi, and 28 remained sterile.

Of spots taken from Schley pecans that were confined with bugs for a period of 4 or 5 weeks 111 were plated on corn-meal agar. Of these, 6 produced colonies of bacteria, 6 grew fungi, and 99 were sterile.

Of spots from Frotscher pecans, grown near Thomasville, Ga., 21 were cultured. Fungi grew on 9 of the spots, none produced bacterial colonies, and 12 were sterile.

Nuts were selected from the same Schley tree on which the cages were attached. Cultures were made of 48 separate spots. The re-

sult of this series was that 1 produced bacteria, 7 grew fungi, and 40 were sterile.

Curtis nuts sent to the writer from Blackshear, Ga., constituted the last series cultured. Of 88 spots that were plated, eight grew bacterial colonies, 20 grew fungi and 60 spots produced no growth.

The record of these laboratory cultures is shown in Table 2.

TABLE 2.—*Record of laboratory cultures of the kernel spots of three varieties of pecans, in November and December, 1921.*

Date cultured, 1921.	Culture media.	Variety and source.	Number of cultures.	Number with bacteria.	Number with fungi.	Number sterile.	Date of final examination.
Nov. 30	Beef agar	Curtis from cages	17	14	1	2	Dec. 6.
Dec. 1	do	do	26	18	6	2	Do.
Dec. 2	Corn-meal agar	do	15	3	12	0	Dec. 7.
Do	Beef agar	Curtis not caged	65	28	9	28	Do.
Dec. 10	Corn-meal agar	Schley from cages	60	6	3	51	Dec. 20.
Dec. 12	do	do	51	0	3	48	Do.
Dec. 16	do	do	25	2	1	22	Do.
Dec. 20	do	Curtis, Blackshear, Ga.	25	2	3	20	Dec. 26.
Dec. 26	do	Frotscher, Thomasville, Ga.	21	0	9	12	Dec. 31.
Do	do	Schley, Thomasville, Ga.	48	1	7	40	Do.
Do	do	Curtis, Blackshear, Ga.	63	6	17	40	Do.
Total			416	80	71	265	

Table 2 indicates that of the 416 kernel spots cultured, 63.7 per cent produced neither fungus nor bacterial growth. The spots most generally producing growths in cultures were those taken from nuts badly injured by many insect punctures. Cultures made from spots that were only slightly or not at all discolored internally generally proved to be sterile.

Since no constant form appeared in the cases where organisms did develop, it was thought highly improbable that kernel-spot could be attributed to any of them, especially since most of the cultures remained sterile. Nevertheless, for the sake of completeness, from 25 to 50 inoculations were made in healthy pecan kernels, employing each of the different forms isolated.

After an interval of seven days, at a temperature of about 22° C., the kernels were all found to be softening more or less around the points of inoculation. None of the inoculations produced the mealy, dry spots which characterize pecan kernel-spot.

Since no form of Coniothyrium was developed from the cultures, an attempt was made to develop it from badly affected kernels by placing them for several days in a moist chamber. Only negative results were produced.

ANALYSIS OF RESULTS.

Of the 313 nuts confined with bugs in the field and 17 in the laboratory (a total of 330), 323 had typical kernel-spot and most of these, especially the Curtis, were very severely spotted. Of the 91 checks in the field and 15 in the laboratory, totaling 106 nuts, all were entirely free from any evidence of kernel-spot. The results reported seem to leave little doubt as to the association of pecan kernel-spot with sucking insects, therefore confirming the investigations of Turner (*6*).

It has been suggested that the insects involved may possibly transmit with their piercing mouth parts some microorganisms to the pecan kernels which cause the characteristic spotting effect. With this supposition in view, the cultural work in the laboratory was carried out. Of portions of over 400 separate spots that were planted on beef and corn-meal agar, more than half proved to be sterile. Rand's Coniothyrium was not observed in any of these cultures. If either a fungus or a bacterium was responsible for the spotting, it is logical to assume that a large percentage of cultured kernel spots would in suitable media develop the causal organism.

Cultures from affected kernels have shown that most of the spots are sterile, while among those developing fungus or bacterial growth no single type of organism has been found constantly associated with the diseased condition. Furthermore, typical kernel spots can be produced readily by confining stinkbugs with immature pecans. It is, therefore, also logical to conclude that pecan kernel-spot can be directly attributed to injuries inflicted by sucking insects, in this case to the southern stinkbug (*Nezara viridula*). The pathological result may be caused by the mechanical rupturing of the host cells, by the sucking up of plant juices, by injection of toxic substances into the tissues, or by the combined result of all three types of injury. No study was made to determine the pathological effect of the punctures, but Figure 5 would lead one to suspect that the injury is due to the extraction of juices from the tissues affected and to the mechanical injury of the cells.

CONTROL MEASURES.

The writer has done no work in view of demonstrating the practicability of controlling pecan kernel-spot. Dr. C. A. Van Duzee, an extensive pecan grower of Cairo, Ga., has been practicing clean cultivation in his orchard for several years. He reports that since this practice was adopted his nuts have been free from kernel-spot.

It is the writer's opinion that clean cultivation can not be recommended unless stable manure can be supplied to the orchard soil

each year. Most southern soils are naturally deficient in organic matter, and unless supplied by means of growing cover crops for green manuring each year the trees will soon suffer.

The cowpea for many years has been the most popular cover crop with pecan growers. It is an easily cultivated legume and adds a large quantity of organic matter to the soil when plowed under. However, it has been observed by the writer, as well as by several growers, and also reported by Turner, that kernel-spot is almost always found more abundantly in orchards planted to cowpeas. This indicates that cowpeas may have to be discarded as a cover crop for pecan orchards and some other luxuriant-growing legume substituted. It appears at present that velvet beans, preferably the bunch variety, will largely take the place of cowpeas in bearing orchards. The velvet bean is a legume, a rank grower, and the writer's observations as well as other available information indicate that it is not a favored host for the stinkbugs. Kudzu and lespedeza are also possible substitutes for cowpeas as summer cover crops in pecan orchards.

The writer made a preliminary investigation during the pecan harvest during the season of 1921, attempting to learn in what section of the tree kernel-spot is most abundant. About 150 nuts were collected from each of five large Frotscher trees averaging from 30 to 40 feet high. The nuts were kept separate from the lower third, middle third, and upper third of the trees. The nuts were cracked and the kernels carefully examined for kernel-spot. Table 3 gives the results.

TABLE 3.—*Sections of pecan trees in which kernel-spot is most abundant.*

Tree.	Affected third (per cent).		
	Lower.	Middle.	Upper.
No. 1	54	46.6	24
No. 2	61.2	18.2	17
No. 3	49.9	19.8	7.6
No. 4	92	68.1	69.6
No. 5	47	0	2
Average	60.2	29.8	24

These results indicate that while the bugs are able to fly to the tops of comparatively high trees, they do most of their feeding on the lower limbs. The evidence procured in this study is not intended to be conclusive, but suggests that in case the growers have an abundance of kernel-spot they could possibly save a portion of their crop by first harvesting the lower part of their trees, keeping these nuts separate and cracking at home or selling to a cracking establishment, thus eliminating what may be a total loss.

It is logical to conclude that greater vigilance in protecting the pecan crop from kernel-spot will have to be observed during seasons following winters with no extremely low temperatures, as there will, no doubt, be a lower mortality of hibernating bugs.

While the information leading to an explanation of the irregular appearance of kernel-spot is meager, it is significant to record that two very severe occurrences of the trouble have followed winters with no extremely low temperatures.

There was a greater occurrence of kernel-spot during the seasons of 1916 and 1921 than during any other years on record for southern Georgia, while in this same region there was very little kernel-spot during the seasons of 1917, 1918, and 1919.

Table 4 shows the absolute minimum temperatures recorded by the United States Weather Bureau at Thomasville, Ga., covering the period from 1914 to 1921, inclusive, together with the prevalence of kernel-spot.

TABLE 4.—*Minimum temperatures and kernel-spot prevalence at Thomasville, Ga., 1914 to 1921, inclusive.*

Years.	Minimum temperature (°F.).	Prevalence of kernel-spot.	Years.	Minimum temperature (°F.).	Prevalence of kernel-spot.
1914–15	23	Abundant.	1918–19	18	Small amount.
1915–16	25	Do.	1919–20	23	Abundant.
1916–17	13	Small amount.	1920–21	29	Do.
1917–18	15	Do.			

The correlation of kernel-spot with temperatures may be only a coincidence. However, it is the writer's opinion that future observation will establish a record showing relationship of occurrence of kernel-spot with winters of no extreme low temperature.

While this investigation seems to clearly demonstrate that the inciting cause of pecan kernel-spot is due to insects, the pathological and physiological changes involved are apparently influenced by the condition of the nuts at the time the punctures are made. Bugs, confined in cages with mature pecan kernels that had been removed from the shells, were observed for several days by the writer. The bugs fed upon the kernels constantly, but produced no evident injuries or spots resembling kernel-spot. This suggested that spots can be produced by the bugs only when the tissues of the kernels are soft and the cell walls can easily be ruptured by the sucking effect of the insects involved.

The history of the investigation of pecan kernel-spot and its pathological effect upon the host plant is parallel in ways to the disease of carnation leaves that Woods (*8*) designated as stigmonose and proved by him to be caused by punctures of aphids, thrips, and red spiders. This carnation trouble had previously been studied by

Arthur and Bolley (*1*) who concluded that the disease was caused by a bacterium. In the case of pecan kernel-spot, Rand first concluded that the trouble was caused by a fungus, and it is now proved by the writer to be caused by insect punctures.

Since the initial cause of pecan kernel-spot is entomological and the result pathological, control measures can possibly best be worked out by considering both factors.

SUMMARY.

Pecan kernel-spot has been reported from North Carolina, South Carolina, Georgia, Florida, Alabama, Mississippi, Louisiana, and Texas.

Owing to the fact that the spots can not be seen until the shells of the nuts are removed, and also because pecans from planted orchards are usually widely distributed in small quantities to consumers, the extent of the loss caused by kernel-spot is difficult to estimate. While the nuts in some orchards will be entirely free from this disease, in other orchards such a large percentage of the nuts will be spotted that the crop will be unmarketable.

Rand conducted a laboratory investigation of kernel-spot in 1912–13 and concluded that it was caused by *Coniothyrium caryogenum*.

The result of the work of Turner in 1917 indicated that the spots were caused by punctures of insects.

In the present investigation, 250 clusters of Schley and Curtis pecans were incased with wire cages. From five to seven specimens of southern stinkbugs (*Nezara viridula* L.) were confined in 200 cages during a period of approximately five weeks for the Schley nuts and two months for the Curtis. Fifty clusters were caged as the others, but no bugs were placed in them. These served as checks. At the end of the experiment none of the checks showed any signs of kernel-spot. Of those nuts caged with bugs, 97.6 were spotted with typical kernel spots.

Nuts with which bugs were confined in a laboratory developed typical kernel spots within 65 hours. No microorganism developed from these spots in Petri dish cultures.

Of 416 cultures made of kernel spots, 80 developed colonies of bacteria, 71 grew fungi, and 265 remained sterile.

No one organism was found constant in pecan kernels affected with kernel-spot. Eight species of fungi and three of bacteria were isolated in this experiment and considered to be saprophytic.

All 11 forms isolated from affected kernels were inoculated into healthy pecans. None produced spots resembling typical kernel-spot.

The cause of pecan kernel-spot is attributed entirely to the mechanical rupturing of the host cells, to the sucking of the plant juices, to the injection of toxic substances into the tissues, or to all three types of injury.

Possible control measures are suggested.

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UNITED STATES DEPARTMENT OF AGRICULTURE

BULLETIN No. 1103

Washington, D. C. July, 1922

SUMMARY OF INSECT CONDITIONS THROUGHOUT THE UNITED STATES DURING 1921.

By J. A. Hyslop, *Entomologist in Charge, Insect Pest Survey, Bureau of Entomology.*

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INTRODUCTION.

The object of the insect-pest survey is to collect accurate and detailed information on the occurrence, distribution, ecology, and relative destructiveness of insect pests throughout the United States, and to study this data from month to month and year to year with relation to the several factors that influence insect abundance. The results to be obtained from this undertaking over a series of years are manifold; we should be able to throw light on the reasons for the cyclic appearance of certain insect pests, the gradual shift of regions of destructive abundance, the limiting barriers to normal dispersal, the directive influences that determine the paths of insect diffusion, and the relation of climatology, geography, topography, and geology, as well as biological complexes, to insect distribution and abundance. This is the necessary foundation for the next advance step in economic entomology, *entomological forecasting.*

The data upon which these summaries are based were collected during the growing season by collaborators, including the field workers of the Bureau of Entomology. Where the review of an insect was drawn largely from the general files of collaborators' reports, no special credit is given in the annual summary. Where the review was drawn from the reports of one or a few workers, acknowledgement is made in footnotes.

Weather data were tabulated, graphically presented, and correlated with the various insect outbreaks by the survey. In these studies an arbitrary year has been adopted, starting with September and running through to September of the succeeding year, instead of using the calendar or fiscal year. Insect outbreaks are undoubtedly predetermined to some extent by the conditions prevailing during the late fall and early winter of the year preceding the actual outbreak and culminate before the end of the calendar year in which the outbreak occurs. The fiscal year ending June 30 is obviously not adaptable to studies relating to insect activity.

In the discussion of insect outbreaks and associated meteorological conditions, it is often convenient to refer to a region rather than to a political unit. For convenience, we have adopted an arbitrary division of the United States into 12 regions. *New England* includes the States usually recognized under this name; the *Middle Atlantic States* include the Atlantic Coast States from New York to Virginia, inclusive, and also West Virginia and Pennsylvania; the *South Atlantic States* embrace the remainder of the Atlantic Coast States, including Florida. These three groups range from sea level to 1,500 feet in elevation, a few isolated mountain ranges running above this elevation, and a large part of the territory is in the Coastal and Piedmont regions.

The *North-Central States* include the two Dakotas, Minnesota, and Wisconsin, the entire region ranging from 500 to 1,500 feet elevation; the *East-Central region* takes in the States in the Ohio River Valley, including Illinois, Indiana, Ohio, Kentucky, and also Michigan; the *West-Central States* include the corresponding territory west of the Mississippi River—Iowa, Missouri, Nebraska, and Kansas; the *lower Mississippi Valley* includes all of the States bordering on the Gulf of Mexico, with the exception of Florida, and also includes Oklahoma, Arkansas, and Tennessee. The Central and Mississippi Valley States are all practically below the 3,000-foot elevation line. The lower Mississippi Valley States and South Atlantic States cover practically the cotton belt.

The *Rocky Mountain States* are Montana, Wyoming, and Colorado. With the exception of a small territory in northeastern Montana, these States are all above the 3,000-foot elevation line. The

Great Basin States are Idaho, Nevada, and Utah, also practically all above the 3,000-foot elevation line. The *Southwestern States* are Arizona and New Mexico. The remaining three States are called the *Pacific Coast States.*

In the temperature and precipitation studies being made by the survey, departures from the normal instead of means are being used. Acute outbreaks undoubtedly are reflections of abnormal meteorological conditions (plus or minus departures) associated with other limiting factors, otherwise they would be chronic conditions and not acute outbreaks.

As data accumulate, the regions over which certain pests are chronic will define themselves, and the normal meteorological range for these regions will be the range of optimum effectives for the given pest. Then a study of the means in other regions should be an index to the possibility of acute outbreaks in these regions. On the other hand, pronounced departures from the normal over the region of optimum effectives for a given pest should be reflected by an abnormal reduction in the abundance of that pest.

During the entomological season of 1921, starting in September, 1920, the weather over the entire region east of the Rocky Mountain and Southwestern States was marked by much wider departures from the normal in both rainfall and temperature than over the Western States. The weather in New England and in the Middle Atlantic and South Atlantic States was characterized by a slight excess of temperature and a more pronounced excess of precipitation in September, 1920, especially in the northern portion. In October the temperature excess increased, while generally over the region there was a very marked deficiency in rainfall. November was generally deficient in temperature, except in the Middle Atlantic States, while the rainfall was excessive. December, January, February, and March were warm throughout the entire region, the excess increasing as the winter advanced. Very serious freezes occurred March 28 and 29 over the lower Middle Atlantic and northern South Atlantic States. The rainfall in December was excessive, except in central and western Virginia, while during the remainder of the winter it was below normal. April was generally warm, with about normal rainfall; two severe killing frosts, however, did further serious damage during this month throughout the Middle Atlantic and South Atlantic States. During May, in New England and the northern Middle Atlantic States, temperature was about normal. In the South Atlantic States the temperature was low and the rainfall excessive. The remainder of the summer was above normal in temperature with the exception of August, which was a little deficient. The rainfall during the summer was very seriously below normal, being relieved in the New England and South Atlantic States in July,

but the drought continued throughout the summer in the Middle Atlantic States.

The conditions throughout the Central and Mississippi Valley States were somewhat similar to those along the Atlantic coast. Here September, 1920, was a little above normal, excess temperatures increasing in October and the moisture falling below normal in the North-Central and East-Central States. November's temperature was slightly below normal throughout the entire region, with the moisture decidedly below normal in the East-Central States. December, 1920, and January and February, 1921, were characterized by increasing excess departures in temperature, running well over 5° and reaching 10° in February in the North-Central and in March in the East-Central States. The rainfall in December, January, and February was generally about normal, with the exception of excessive rainfall in December in the lower Mississippi Valley. March was characteristically a wet month throughout the entire region. April was generally warm, except in the Gulf States, as was also May. Serious frosts occurred over the East-Central and West-Central States in the latter part of March and first part of April, however, destroying much of the fruit. The rainfall was above normal in the North-Central States in April, while in the East-Central, West-Central, and lower Mississippi Valley May was very dry. June, July, and August were above normal in temperature throughout the entire Central and Mississippi Valley regions, the moisture being below normal in June in the North-Central and East-Central States, about normal in the West-Central States, and above normal in the lower Mississippi Valley. In July the rainfall was below and in August above normal in the North-Central and East-Central States, while the lower Mississippi Valley was experiencing a drought. September, 1921, throughout this entire territory was above normal in both temperature and rainfall, with the exception of a deficiency of rainfall in the lower Mississippi Valley.

The regions in and west of the Rocky Mountains also had generally mild winter, with but few marked departures from the normal.

The Pacific coast had excessive precipitation in December, 1920, while the Southwest had a similar excess in June, July, and August following a dry winter and spring. September, 1921, was dry throughout this entire territory with the exception of the Pacific Coast States and the temperature was normal or slightly below.

The generally mild winter of 1920 and comparatively warm spring of 1921 seemed to have been particularly favorable for the development of lepidopterous insects. The corn earworm, European corn borer, cankerworms, webworms, cutworms, alfalfa caterpillars, and many other species were abnormally abundant in various parts of the country. The cotton worm made one of its periodic northern

sojourns, appearing in September in Louisiana and Texas and in October as far north as Michigan and New York State.

The clover-leaf weevils were very troublesome in the East-Central and West-Central States and were also reported from the northern Pacific coast.

The plum curculio was quite troublesome in the New England, Middle Atlantic, and East-Central States.

Blister beetles were extremely abundant throughout the entire country east of the Rocky Mountains, reports of serious depredations having been received from New York, Indiana, Illinois, Ohio, Missouri, Mississippi, South Dakota, and Nebraska. Dr. Arthur Gibson, Dominion entomologist of Canada, says:

> These insects appeared in numbers in the various Provinces as follows: In New Brunswick and other sections of eastern Canada the ash-gray blister beetle, *Macrobasis unicolor* Kby., caused important injury to the foliage of potatoes. In the prairie Provinces the western blister beetle, *Cantharis nuttalli* Say, occurred in numbers on beans and certain other crops. *Epicauta puncticollis* Mann. was reported from Alberta, where it was found attacking potatoes and beans. In Manitoba, *Macrobasis murina* Lec. was found in numbers on the foliage of the same plants.

The pea aphis was reported as very destructive in Oklahoma, Kansas, Missouri, and Illinois very early in the season, while during May and June reports of serious depredations by this pest were received from Oregon, Colorado, and Nebraska.

With the extremely fragmentary data on ecological conditions throughout the country at present available, it is obviously necessary to limit the annual summary to the few insects that are attracting the particular attention of the working entomologists in the several States. Therefore, in the following pages the entomological situation for the season of 1921 has been reviewed as it relates to 19 of the more serious and conspicuous insect pests of this country.

CORN EARWORM.

(*Heliothis obsoleta* Fab.)

During the past season the corn earworm has been one of the most serious and important pests. It has been of unusual abundance over much of its range, and has extended its depredations far to the north of its usual limits.

In New England the pest was reported from Maine for the first time since 1915, and the second time since 1892. Doctor Patch reported rather serious infestations over the southern half of the State, covering much of the important sweet-corn canning region. In Massachusetts the only previous records of the occurrence of this insect since 1886, when the State experiment station was organized, are from the extreme southern border of the State. This year the

pest swarmed over the entire State and in many cases as high as 95 per cent of the ears of sweet corn were infested. The pest was also reported as much more numerous and destructive than usual in Connecticut, and a single report was received from Newfane in the southern part of Vermont.

In the Middle Atlantic States the outbreak was unusually severe. Pennsylvania reported the insect as abnormally destructive over the entire corn-growing area. A similar report was received from New Jersey, where an actual count showed sweet corn damaged to the extent of 30 per cent and field corn 15 per cent. In New York the infestation ran into the extreme northeastern corner on the Canadian boundary. In Delaware the demonstration plats at the experiment station showed from 10 to 15 per cent loss, and the pathologist of the experiment station reported that usually *Fusarium moniliforme* Shel., *Cephalosporum sacchari* Butler, and *Diplodia zeae* Lev. are associated with corn earworm damage. Virginia and West Virginia reported the infestation general, Virginia estimating that from 3 to 5 per cent of the corn was lost because of the ravages of this insect, while West Virginia recorded 90 to 95 per cent of the ears infested by actual count.

In North Carolina the pest was generally distributed, but not reported as unusually abundant. In South Carolina the infestation was most serious along the coastal region, extending from Aiken to Horry Counties and southeastward to the coast, the center of the infestation being in Barnwell County. In Florida the pest was particularly abundant and destructive. By actual count the crop was found to be damaged in some places from 10 to 25 per cent, while in the region about Sandford fields were completely destroyed.

In the North-Central States the infestation was unusually severe. This pest, though usually present, rarely attracts any considerable attention. In Michigan the entire lower peninsula was generally infested, the infestation ranging from 10 to 75 per cent of the ears. The southern half of Minnesota, north to a line extending from Clay to Chisago Counties, was infested. On the experimental plats at the station an actual count showed that from 20 to 30 per cent of the ears were infested. In Wisconsin the southeastern counties were quite generally infested north to Adams County, and west to and including Dane County. In North Dakota the insect was unusually abundant in the southeastern part, and in South Dakota it was serious in the eastern tier of counties, and also in the central and west-central counties.

Arthur Gibson, Dominion entomologist, reports that by far the worst infestation of which they have any record occurred in Canada in 1921. In Ontario late sweet corn was injured in some fields to the extent of 25 per cent of the crop. In certain districts the ears were

infested to such an extent that they were refused by canning companies. The pest was also very serious in the Provinces of Quebec, Manitoba, and British Columbia.

In the East-Central States the damage was of record importance. In Ohio the outbreak was worse than any since 1904, and probably the most severe ever recorded. Field corn was reduced from 5 to 10 per cent of its actual bulk, and in the canning section sweet corn was damaged to about 50 per cent. In Indiana the outbreak was the worst in the past 10 years, the infestation estimated as ranging from 5 to 30 per cent. In this State the ear rots were also reported as accompanying the earworm injury. In Illinois the outbreak was unusual; 75 per cent of the sweet corn was reported as infested and 5 per cent of the grain crop destroyed. Here and in Indiana the outbreak was most conspicuous in the northern half of the State. In Kentucky the outbreak was the most severe ever observed by Professor Garman.

In Iowa the outbreak was the most serious in the experience of the reporter, which covered six years. In Nebraska the infestation was quite general, being worst in the east and east-central parts of the State. The most serious corn earworm outbreak ever recorded in Missouri occurred during the past year, the infestation being practically 100 per cent throughout the State. In Kansas the outbreak was not unusual, destruction of the corn ranging from 3 to 5 per cent. In the western part of the lower Mississippi Valley a similar condition prevailed to that in Kansas, the outbreak being about normal.

In the eastern part of the lower Mississippi Valley the outbreaks ranged from normal to slightly above normal. In Louisiana tomatoes in the experiment station plats were damaged from 30 to 35 per cent. In Alabama the pest was recorded as unusually abundant, while in Arkansas it was not more destructive than during average years.

In the Rocky Mountain region no damage was experienced, except in the eastern part of Colorado, east of a line extending from Larimer to Huerfano Counties, where the pest is usually quite destructive.

In the Great Basin no outbreaks were reported.

In the Pacific coast region, Oregon reported the insect as fairly abundant in the Willamette Valley, where it has been one of the major corn pests since 1898. A remarkable feature of this insect's habits in Oregon is that it is never recorded as attacking tomatoes, beans, or, in fact, any plants except corn. In California this insect was recorded for the first time as attacking cotton, reports having been received from Glenn and Kern Counties during 1921; the outbreaks, however, were not serious. In the canning sections of central and southern California the pest was very serious and

caused considerable loss. In the coast region about San Francisco Bay the corn earworm has become so serious a pest that the growing of sweet corn has been discontinued.

One of the striking features of this year's corn earworm outbreak was the rather unusual damage occasioned to alfalfa, reports of serious damage to this crop having been received from Illinois, Kansas, and Kentucky. Injury to vetch was reported from Alabama. Another unusual feature was the serious damage done to greenhouse crops in Indiana; roses, chrysanthemums, carnations, and geraniums suffered severely from the feeding of these larvæ on the flower buds and stems, the damage ranging from 10 to 90 per cent of the crop.

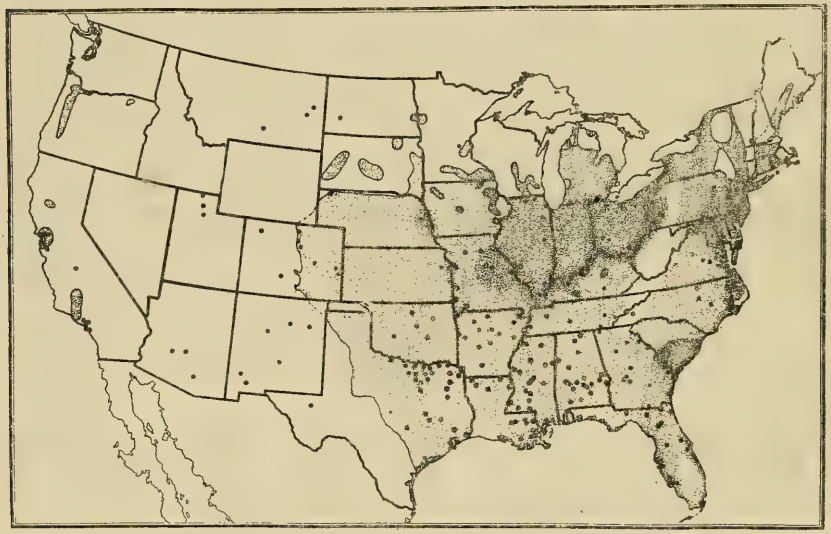

FIG. 1.—Geographical distribution of the corn earworm in the United States: Heavily shaded area, very seriously infested in 1921; lighter shading, area of appreciable damage in 1921; black dots, localities where serious outbreaks have occurred previous to 1921.

Table 1 gives some impression of the seriousness of this pest during the past season. The figures on the bushels of field corn produced in 1921 were provided by the Bureau of Markets and Crop Estimates. The percentages of damage were obtained from actual counts by the entomological collaborators of the survey, or were estimated from the percentage infestation obtained by actual count. No attempt has been made to reduce this loss to dollars and cents, but the damage to corn ran well over 175,000,000 bushels.

The figures on sweet corn are very fragmentary, but in the four States sending in estimates the damage amounted to over $1,500,000.

The accompanying map (Fig. 1) indicates the localities from which this insect has been reported, both in the past and during the season of 1921, the heavily shaded area indicating the region of

unusual abundance in 1921, the lighter shading indicating appreciable damage in 1921, and the black dots, localities of serious infestation in previous years drawn from literature.

TABLE 1.—*Estimated damage to field corn by the corn earworm.*

State.	Bushels in crop, 1921.	Percentage infested in 1921.	Percentage damaged in 1921.	Estimated bushels damaged, 1921.
Illinois	306,000,000	.....	5	15,300,000
Indiana	169,800,000	.....	[1] 7	11,886,000
Ohio	159,300,000	.....	7	11,151,000
Missouri	182,900,000	100	[1] 10	18,290,000
Minnesota	140,500,000	20–30	[1] 1	1,405,000
Kansas	102,100,000	.....	4	4,084,000
Michigan	66,400,000	10–75	[1] 1	664,000
Virginia	47,600,000	.....	4	1,904,000
West Virginia	20,100,000	90–95	[1] 4	804,000
New York	36,700,000	30–40	[1] 2	734,000
New Jersey	11,300,000	.....	[1] 15	1,695,000
Massachusetts	3,100,000	5–95	[1] 2	62,000
Total for above 12 States	1,245,800,000	.....	.....	67,979,000
United States	3,080,400,000	.....	.....	175,612,000

[1] Estimated.

HESSIAN FLY.

(*Phytophaga destructor* Say.)[1]

The Hessian fly outbreak which threatened during the summer and fall of 1920 has declined to a point that warrants the assumption that but little damage will be done by this pest during the summer of 1922. The fly was of minor importance in comparison with the great outbreak of 1915 and 1916.

In the territory east of the Appalachian Mountains the spring brood was very serious in North Carolina, South Carolina, and tidewater sections of eastern Maryland. In North Carolina the damage was confined to the west-central part of the State, while the outbreak in South Carolina was contiguous with that in North Carolina. In the latter State the crop failure was complete in places. The fall brood was generally very light over this region, with the exception of a few localized infestations in New York and tidewater Maryland. In New York the average infestation in the 14 principal wheat-growing counties amounted to 7.33 per cent.

Among the East-Central States, Ohio reported that a midsummer survey, carried on in 31 counties, showed an average of 17 per cent infestation as against 44 per cent infestation in 1920. In nine northwestern counties the infestation ran as high as 35 per cent. In these counties, however, parasitism was very high, averaging from 50 to 60 per cent.

[1] From reports of W. R. Walton, Bureau of Entomology, and survey collaborators in the several States.

In Indiana a large spring brood was reported early in April, 99 per cent of the stalks being infested in places in the southern part of the State. During June much fallen wheat was observed. In Illinois the infestation was slight except in a few of the west-central counties along the Mississippi River. Iowa reported that the Hessian fly was on the increase in the southeastern and south-central counties, the winter wheat examined on December 22 being very badly infested.

Minnesota reported practically no flies, while Wisconsin reported no serious infestation, but flies present over the southern tier of counties.

According to W. H. Larrimer, Bureau of Entomology, the general infestation throughout the Central States, although showing some irregularities, has declined greatly, due no doubt to the response of wheat growers to the efforts of extension and other entomologists of Ohio, Indiana, Illinois, and Missouri in cooperation with the Federal Bureau of Entomology. The recommended safe-sowing dates held remarkably well in the fall of 1921 and there seems to be no doubt that if wheat growers had not adopted the recommendations a heavy infestation would have occurred in practically all early sown wheat. There was no indication of a late wave of the Hessian fly such as existed during the fall of 1920. A slight supplemental brood, originating in volunteer wheat, was present in local areas from La Fayette, Ind., southward, but in general the status of the fly during the fall of 1921 was considerably less menacing than was the case early in the spring. Practically all wheat sown before these dates began the winter in splendid condition, and practically no Hessian fly infestation occurred in this grain. A slight menace to this grain exists in some regions in the volunteer wheat. Parasitism is rapidly increasing.

In the area west of the Mississippi River, according to J. R. Horton, Bureau of Entomology, no serious infestations occur at the present time, except in northeastern Oklahoma, where local heavy infestations are indicated. Conditions in Kansas are especially promising so far as the Hessian fly is concerned. The heaviest infestation in the fall examinations was in Sedgwick County, which showed an infestation of between 3 and 4 per cent. The prospects for a crop, however, are not as favorable as might be expected, owing to adverse meteorological conditions.

Missouri reported early in the season the worst outbreaks since 1916, Doctor Haseman stating that counts made in July in 29 counties averaged 21 per cent of the straws infested, the heaviest infestation being in the 14 central counties, where the infestation ran as high as 36 per cent, while the infestation in the western counties dropped to 11 per cent. The winter wheat was not sown

CORRECTION SLIP FOR DEPARTMENT BULLETIN 1103.

On page 10 the fifth sentence in the third paragraph should read as follows:

"Practically all wheat sown after these dates began the winter in splendid condition, and practically no Hessian fly infestation occurred in this grain."

until after the fly-free date in the northern part of the State north of the Missouri River. This was partly due to the efforts of the Hessian fly campaign and was also due, in part, to the heavy rains which delayed plantings in many localities. South of the Missouri River the rains abated early enough to induce a great deal of planting from one to three weeks before the fly-free date, and very heavy infestation of the Hessian fly was reported about the middle of October in this region. North of the river the volunteer grain was also badly infested.

In Nebraska the Hessian fly was present in rather menacing numbers early in the spring. By midsummer a rather serious spring

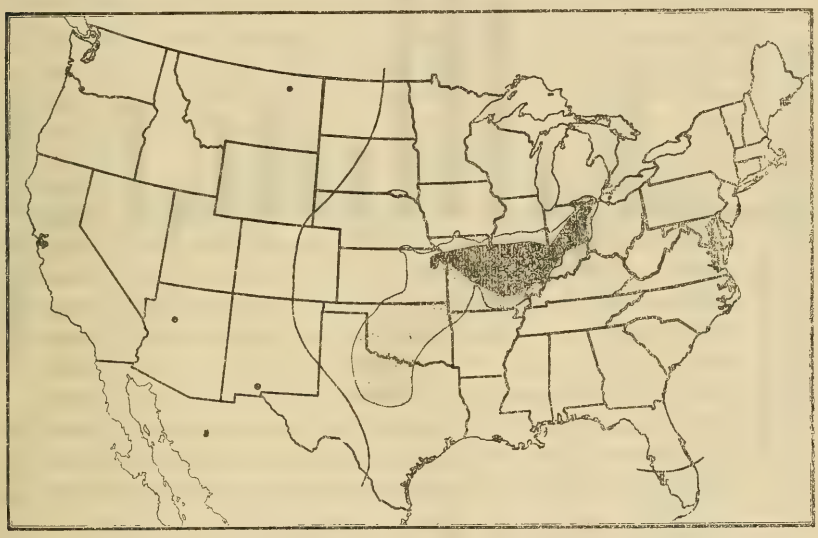

FIG. 2.—Geographical distribution of serious chinch-bug infestations in the United States in 1921: Solid-colored area, very seriously infested; shaded area, general infestation; lines limit western and southern known distribution; dots are records from literature.

brood was present all over the eastern counties. The September examinations, however, showed that the fly was only present in serious numbers in a few scattering localities.

On the Pacific coast the fly was reported as less serious than in 1920, but much lodging of wheat occurred in the Willamette Valley due to unusual winds where slight fly infestation occurred.

CHINCH BUG.

(*Blissus leucopterus* Say.)

The chinch bug appeared as a serious pest during the season of 1921 over only a small part of its normal range of destructive abundance. The area seriously infested extended in a southwesterly-

northeasterly direction, from the north-central part of Texas, across the center of Oklahoma, eastern Kansas, most of Missouri, southern Illinois, central Indiana, into the northwestern corner of Ohio and the southern tier of counties in Michigan.

The very seriously infested area (Fig. 2) was confined almost exclusively to Indiana, Illinois, and Missouri. In Indiana the pest has been steadily on the increase in destructive abundance since 1917. In 1917 very few chinch-bug cases were reported to the station; reports in numbers started to come in during the season of 1918, were almost

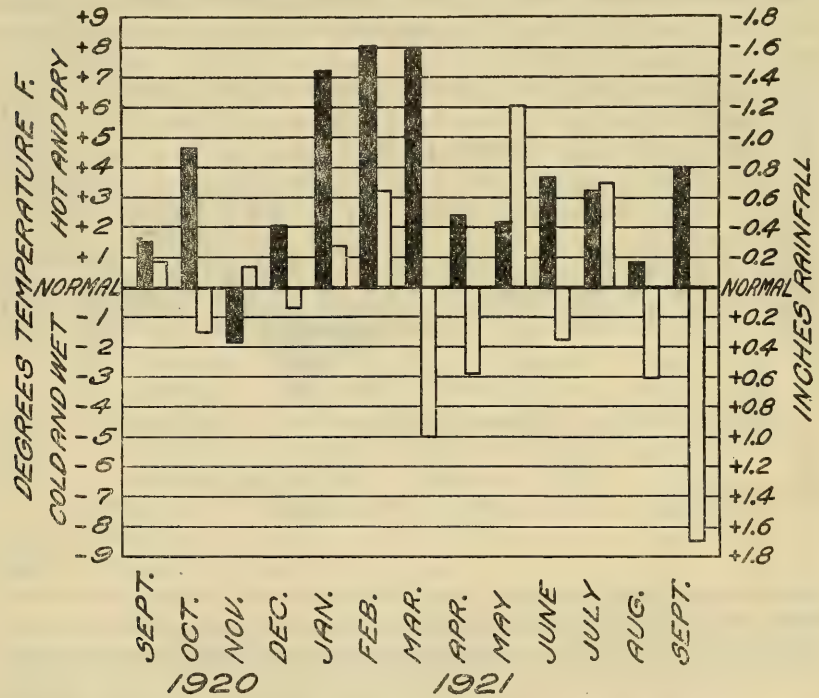

FIG. 3.—Monthly departures from normal temperature (solid black) and rainfall (white) for the fall of 1920, the winter of 1920–21, and the growing season of 1921 in the region infested by the chinch bug during 1921. (See also Table 2.)

doubled during 1919, and quadrupled in 1920. During 1921, 52 counties were infested. The northern limit of the infested area in Indiana extended from the north-central part of Steuben County almost directly southwestward to the southern border of Warren County, while the southern limit extended from the center of Union County, through the southeastern corner of Morgan County, to the southeastern corner of Posey County. The area of severe infestation ran parallel to these two lines, running on the north from the center of DeKalb County to the southern part of Vermillion County, and on

the south from the center of Wayne County through the northwestern corner of Johnson County to the northwestern corner of Gibson County.

In Illinois the infested area was continuous on the east with that of Indiana, the northern boundary extending across the State from the southern third of Iroquois County to the northern third of Hancock County, and on the south to the southern border of the State. The seriously infested area extended from the southeastern corner of Edgar County, through the southern third of Piatt County and the center of Cass County, to the center of Adams County, southward to the southern borders of Galla, Hamilton, Franklin, and Jackson Counties. During the early fall the number of bugs was materially decreased by heavy rains, but the last observation indicated that there were enough of these insects in hibernation to cause serious damage during the coming growing season over a large part of the southern half of Illinois.

In Missouri the infested area covered the greater part of the State. The only regions from which no reports of infestation were received were Pemiscot County in the southeastern corner, a small area including Tanney and Ozark Counties on the southern border and extending northward to Laclede County, and a few counties along the northern border. The most seriously infested area was continuous with that in Illinois, narrowing in a northwesterly direction.

A small area in Kansas covering the greater part of Atchison and Jefferson Counties was most seriously infested, while a generally moderate infestation covered the eastern third of the State. The infestation in Oklahoma was not unusual and covered an area extending diagonally across the State, on the north from Woods County to the southern third of Ellis County and south from Delaware County to the southwestern corner of Bryan County. This outbreak, though not severe this season, indicated a decided increase of this pest.

In Nebraska there was an infestation in the southern half of Thayer and Jefferson Counties. A rather unusual outbreak occurred late in the season in the northeastern part of the State in Knox County, the bugs first appearing in barley and later moving to the corn, where they did a considerable amount of damage.

In Ohio there were apparently more chinch bugs than there have been since the seasons of 1904, 1905, and 1906, extending over practically all of the western part of the State, the most serious area being confined to Defiance, Pauling, and Williams Counties, in the northwestern corner.

In Iowa this insect appeared for the first time in 20 years in the south-central part in Decatur County.

The northern limit of the outbreak was the southern tier of counties in Michigan, including the greater part of Lenawee and Hillsdale Counties, and the southern part of Branch, St. Joseph, and Monroe Counties. As far as the records of the station go, this outbreak is the first that has occurred in Michigan since 1887.

An isolated outbreak of minor importance appeared in South Dakota in the southeastern part covering Bon Homme and Charles Mix Counties. This was the first outbreak during at least the past 12 years.

In Texas the only report of serious damage was received from Hill County. The pest occurred in normal numbers, however, over the region usually infested.

The temperature over the whole infested territory was above normal during the early fall of 1920. November, however, had an average deficiency of 1.8°, the deficiency being greatest in Missouri, Kansas, and Oklahoma where it was between 3° and 5°. The winter of 1920–21 was unusually warm, the average departures during January, February, and March being over 7° F. The spring and summer were also warmer than usual. (See Fig. 3 and Table 2.)

The rainfall over this region was about normal during the fall and winter, being generally below normal during the winter months. In March wet weather set in, the average being over an inch above normal during this month. April was also above normal, while May was quite dry throughout the entire region, the deficiency being 1¼ inches. June and July were dry throughout most of the region, although there were heavy rains in June in Oklahoma and Texas, where the excess was between 3 and 4 inches, bringing the average for the region above the normal. August and September were generally wet, September having an excess of precipitation of 1.69 inches. The dry periods in May and July were advantageous to the development of young chinch bugs while the wet weather of August and September undoubtedly did much to reduce the infestations of the fall brood over much of the infested region.

The accompanying map (Fig. 2) indicates the areas generally infested in 1921 (shaded), the area of most serious damage in 1921 (black), and the line limiting the western known distribution of the pest. The black dots are isolated reports, from literature, beyond this western limit of distribution.

TABLE 2.—*Monthly departures from normal temperature and rainfall for the fall of 1920, the winter of 1920–21, and the growing season of 1921 in the region infested by the chinch bug during 1921.*

DEPARTURES (IN DEGREES FAHRENHEIT) FROM NORMAL TEMPERATURE.

State.	1920				1921								
	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.
Michigan	+2.4	+7.3	−0.5	+4.3	+6.1	+7.5	+6.9	+6.3	+3.6	+6.1	+7.0	+0.7	+5.0
South Dakota	+2.2	+5.9	−.5	+1.4	+10.5	+12.4	+6.5	+2.4	+1.4	+6.9	+3.8	+.9	+1.0
Iowa	+3.1	+6.9	+.4	+2.5	+10.5	+10.5	+9.5	+3.7	+2.8	+5.6	+3.8	+.3	+3.9
Nebraska	+1.4	+4.2	−1.4	+1.2	+8.4	+9.1	+7.3	+1.0	+1.6	+3.8	+1.8	+1.1	+2.7
Missouri	+1.4	+4.3	−3.5	+2.6	+7.2	+9.1	+8.5	+.9	+2.0	+3.4	+2.9	+.8	+4.7
Kansas	+.6	+3.8	−4.4	+3.2	+6.9	+9.0	+7.3	+.9	+2.4	+1.6	+1.1	+1.4	+4.6
Ohio	+.8	+5.3	−.8	+2.9	+4.7	+6.4	+10.1	+5.3	+1.3	+4.2	+4.2	−1.1	+4.6
Indiana	+1.6	+5.9	−.8	+1.3	+5.6	+7.0	+10.1	+3.9	+2.1	+4.7	+5.1	−.5	+4.7
Illinois	+2.6	+5.7	−1.3	+2.8	+7.8	+8.7	+9.9	+3.9	+2.9	+5.2	+4.8	+.1	+4.6
Oklahoma	+.4	+2.1	−4.2	+2.0	+5.7	+6.1	+4.7	−.7	+2.5	+.6	+.4	+2.1	+5.0
Texas	+1.8	+.5	−2.9	+.5	+5.7	+3.6	+5.6	−1.8	+.6	−.8	+.0	+1.7	+4.0
Regional mean	+1.6	+4.7	−1.8	+2.2	+7.2	+8.1	+7.8	+2.3	+2.1	+3.6	+3.2	+.7	+4.0

DEPARTURES (IN INCHES) FROM NORMAL RAINFALL.

State.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.
Michigan	−0.57	−0.84	−0.24	+1.25	−1.18	−0.77	+1.61	+1.15	−1.48	−0.92	−0.62	+1.29	+0.73
South Dakota	−.39	−.48	+.56	+.02	−.20	−.41	+.21	−.34	+.02	−1.59	+.76	+.52	+2.07
Iowa	−.06	−.33	+.68	−.06	−.54	−.38	−.20	+.48	−.34	−.62	−1.43	+1.36	+3.36
Nebraska	−.93	+.60	+.42	+.04	+.18	−.30	−.45	−.53	+.01	−1.44	+.67	−.29	+.19
Missouri	+.92	+.25	−1.09	−.22	−.38	−1.33	+1.68	+1.52	−1.20	+1.15	−1.77	+1.63	+3.15
Kansas	+.22	+1.04	+.19	−.07	+.37	−1.01	+.06	+.72	−1.31	+.81	−.37	+.26	+.58
Ohio	−.16	−.59	+.30	−.57	−.69	−.58	+2.47	+.67	−.43	−.93	−1.03	+.71	+1.67
Indiana	−.18	−.33	−1.04	+.53	−.74	−.92	+2.01	+.81	−1.81	−.33	−1.27	+2.09	+2.58
Illinois	−.87	−.32	−1.44	+.65	−.93	−1.26	+2.10	+1.39	−2.11	−.08	−1.57	+1.81	+3.10
Oklahoma	+.65	+2.92	−.29	+.47	+.84	+.13	+1.05	+.18	−2.84	+4.24	−.60	−1.11	+.01
Texas	−.65	+1.20	+.27	−.66	+.04	−.29	+.82	+.46	−1.74	+3.39	−.42	−1.60	+1.20
Regional mean	−.18	+.28	−.15	+.12	−.29	−.64	+1.03	+.59	−1.20	+.33	−.69	+1.02	+1.69

GREEN BUG.

(*Toxoptera graminum* Rond.)[2]

The green bug was of comparatively little importance during the season of 1921. Early in the season the pest appeared in rather threatening numbers in parts of Texas, Oklahoma, and Kansas, but dry weather later in the season reduced the injury to a negligible factor. The areas from which reports of infestation were received include a narrow strip of territory extending from Bell and Coryell Counties in Texas northward through Ellis, Denton, Collin, and Grayson Counties, into Bryan County, Okla. Oats were seriously injured in some of the northern counties of Texas where the loss was estimated at about 25 per cent. Quite serious infestations were also recorded from north-central Oklahoma, including Oklahoma, Logan, Noble, and Tulsa Counties. (Fig. 4.)

In Kansas the infestation was confined to the southeastern tier of counties, being most severe in Cherokee County and diminishing westward to Cowley County. Sumner County was practically free of the green bug.

[2] Drawn largely from the reports of J. R. Horton, S. J. Hunter, R. H. Beamer, J. W. McColloch, C. E. Sanborn, and E. E. Scholl.

A few isolated green-bug outbreaks were reported from Missouri, one in Jasper County, continuous with that in Cherokee County, Kans., and two isolated outbreaks in the southeastern part, in Perry and Mississippi Counties.

In the three States infested by the green bug during 1921 the weather was very uniform, there having been a period of cold weather in November, 1920. (See Table 3 and Fig. 5.) This was followed by a very mild winter, January, February, and March running to 6° F. above normal while February in Kansas was 9° F. above normal. The spring started out with decided excess tempera-

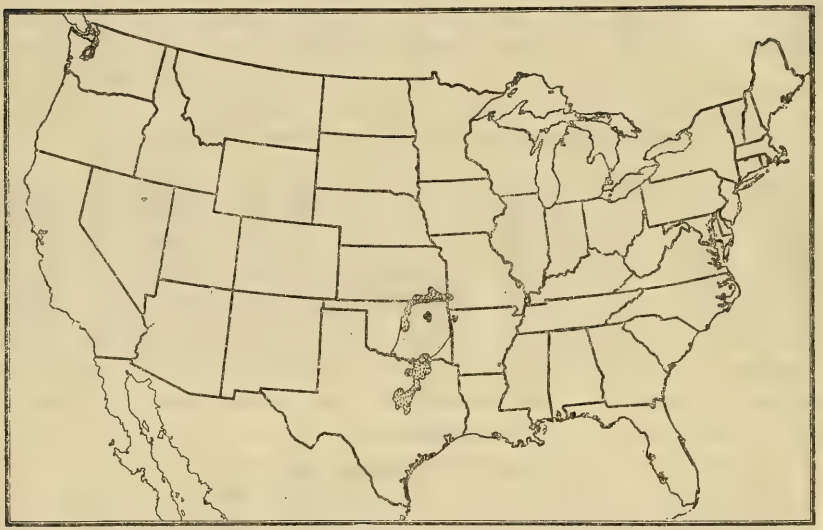

FIG. 4.—Geographical distribution of the green bug in the United States in 1921: Heavy shading indicates serious damage; light shading, threatened damage.

ture in March. This was followed by a rapid drop in April which carried it below the normal in both Oklahoma and Texas. The spring and early summer were very nearly normal, the temperature rising during August and September to slightly above normal.

The rainfall throughout this region was above normal throughout most of the winter with the exception of the month of February. (See Table 3 and Fig. 6.) The spring was about normal up to May when a very decided drought set in. This was followed, however, in June by an excess of rainfall in Oklahoma and Texas of over 3 inches. August and September in these last two States were very dry while Kansas was about normal.

Figure 4 indicates the area of threatening outbreaks in the spring of 1921 (shaded lightly) and the area where damage was recorded (heavy shading).

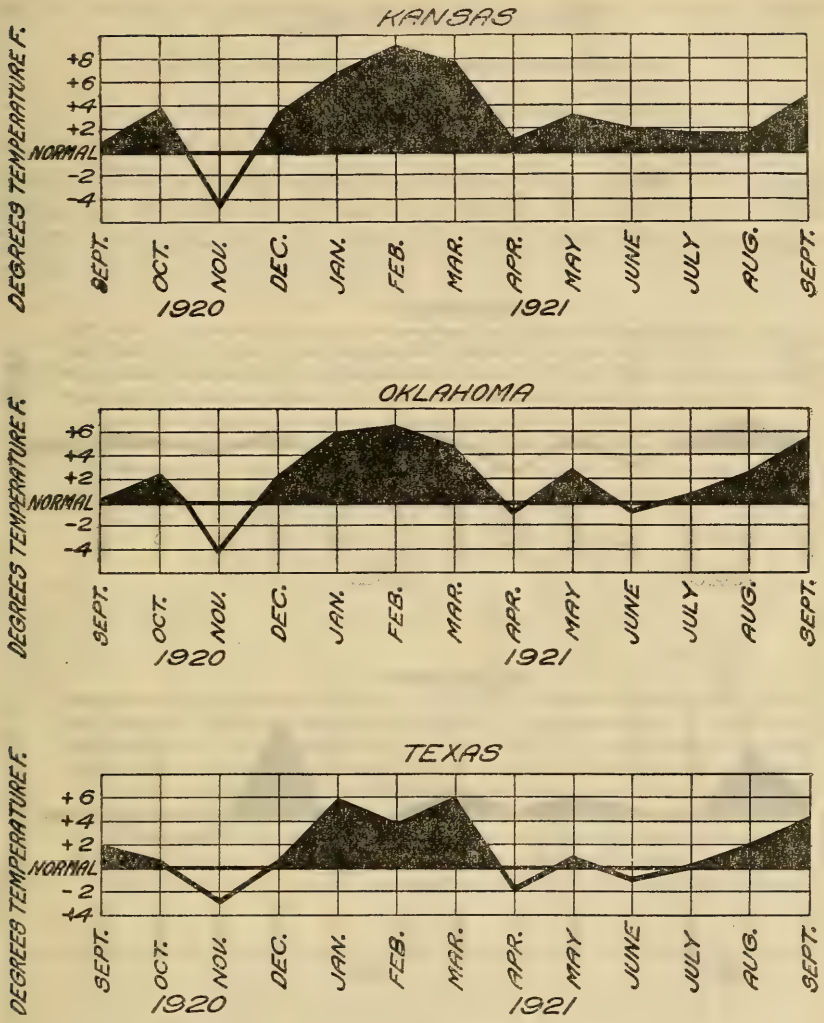

FIG. 5.—Monthly departures from normal temperature for the fall of 1920, the winter of 1920–21, and the growing season of 1921 in the region infested by the green bug in 1921. (See also Table 3.)

TABLE 3.—*Monthly departures from normal temperature and rainfall for the fall of 1920, the winter of 1920–21, and the growing season of 1921 in the region infested by the green bug in 1921.*

DEPARTURES (IN DEGREES FAHRENHEIT) FROM NORMAL TEMPERATURE.

	1920.				1921.								
	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.
Kansas	+0.6	+3.8	−4.4	+3.2	+6.9	+9.0	+7.3	+0.9	+2.4	+1.6	+1.1	+1.4	+4.6
Oklahoma	+ .4	+2.1	−4.2	+2.0	+5.7	+6.1	+4.7	− .7	+2.5	− .6	+ .4	+2.1	+5.0
Texas	+1.8	+ .5	−2.9	+ .5	+5.7	+3.6	+5.6	−1.8	+ .6	− .8	+ .0	+1.7	+4.0
Regional mean	+ .9	+2.1	−3.8	+1.9	+6.1	+6.2	+5.8	− .5	+1.8	+ .0	+ .5	+1.7	+4.5

TABLE 3.—*Monthly departures from normal temperature and rainfall for the fall of 1920, etc.*—Continued.

DEPARTURES (IN INCHES) FROM NORMAL RAINFALL.

	1920				1921								
	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.
Kansas	+0.22	+1.4	+0.19	−0.07	+0.37	−1.01	+0.06	+0.72	−1.31	+0.81	−0.37	+0.26	+0.58
Oklahoma	+ .65	+2.92	− .29	+ .47	+ .84	+ .13	+1.05	+ .18	−2.84	+4.24	− .60	−1.11	+ .01
Texas	− .65	+1.20	+ .27	− .66	+ .04	− .29	+ .82	+ .46	−1.74	+3.39	− .42	−1.60	+1.20
Regional mean	+ .07	+1.72	+ .05	− .09	+ .41	− .39	+ .64	+ .45	−1.96	+2.81	− .46	− .81	+ .59

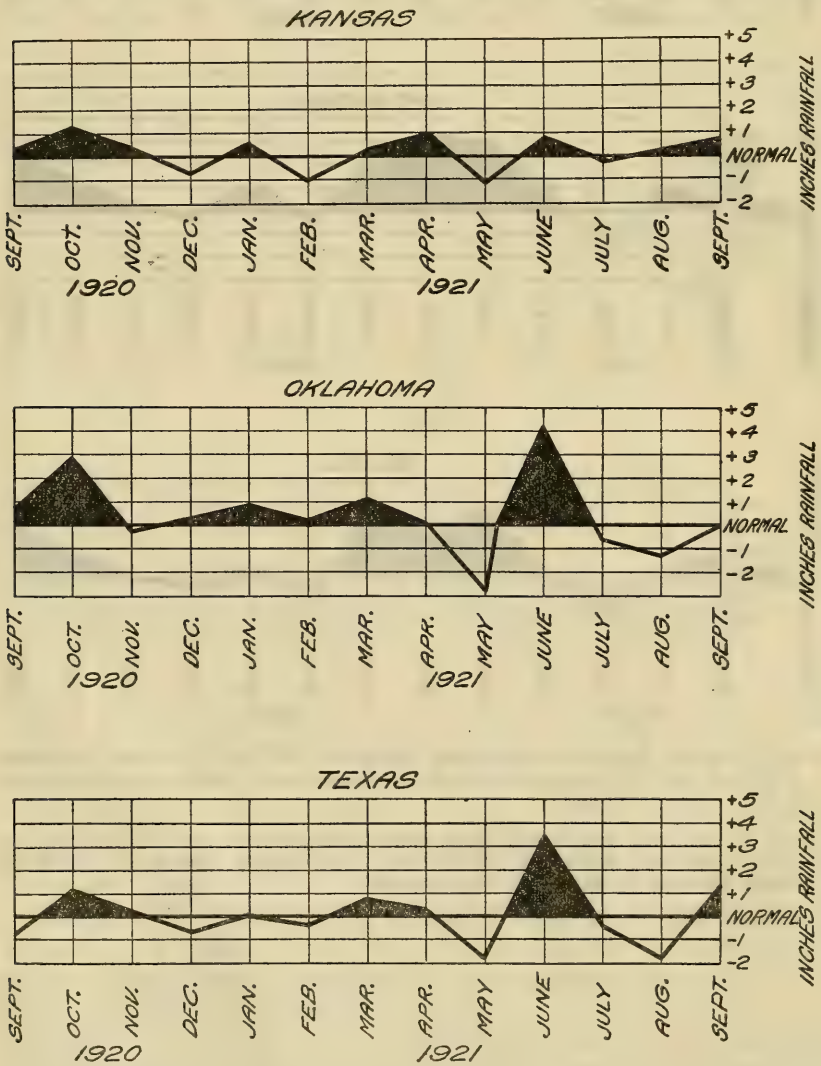

FIG. 6.—Monthly departures from normal rainfall for the fall of 1920, the winter of 1920–21, and the growing season of 1921 in the region infested by the green bug in 1921. (See also Table 3.)

PALE WESTERN CUTWORM.

(*Porosagrotis orthogonia* Morr.)

During the season of 1921 the pale western cutworm was again seriously abundant in parts of the Rocky Mountains and North-Central States, the most serious damage being reported from Montana. Rather extensive outbreaks occurred in southwestern North Dakota, and the pest was generally destructive over the winter-wheat sections of eastern Colorado.

Arthur Gibson, Dominion entomologist, reports:

Of the cutworms the chief species reported was the pale western cutworm which devastated large areas of wheat land in southern Alberta and also caused some damage in certain sections of southern Saskatchewan.

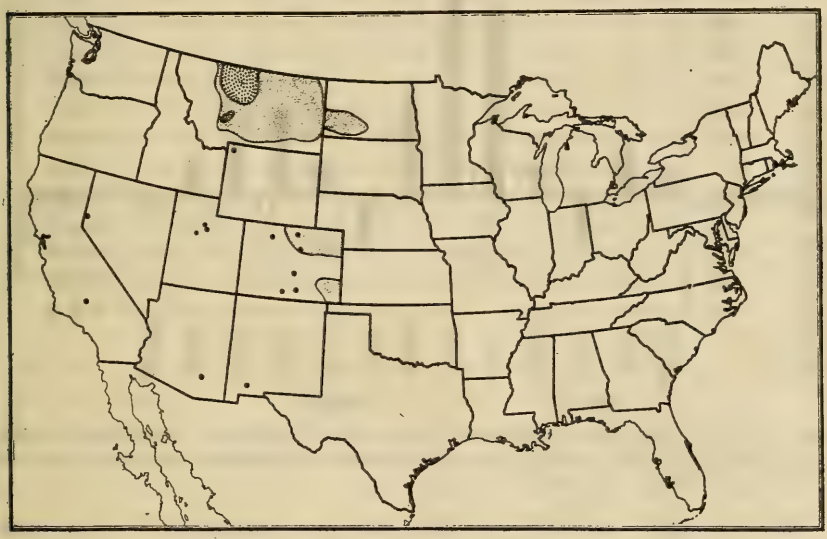

FIG. 7.—Geographical distribution of the pale western cutworm in the United States in 1921: Coarsely shaded area, very seriously infested; finely shaded area, generally infested; black dots, records from literature.

In Montana the area of general distribution extended over the greater part of the State from the eastern border westward to the center of Glacier National Park, and Jefferson County. During 1921 the pest destroyed from 33 to 35 per cent of the seeded area in Glacier National Park and in Toole, Liberty, Hill, and Cascade Counties, and damaged from 6 to 15 per cent of the seeded area in Dawson, Prairie, and Fallon Counties in the east-central part of the State and Broad Water and Jefferson Counties in the southwestern part. The outbreak as a whole, however, seemed less serious than the outbreak of 1920.

In North Dakota the outbreak was confined to the area south of Golden Valley and Oliver Counties and west of Morton and Grant

Counties. The larvae were so numerous that by actual count as many as 17 were found to a square foot in some wheat fields, while the average over the entire infested region was about five cutworms in this same area. They were also very destructive to young corn.

In Colorado this insect was somewhat more active than usual, particularly in the winter-wheat area east of a line extending from Jackson County to Graham County, in the northeastern part, and Crowley and Las Animas Counties in the southeastern part.

This pest has been recorded in literature from Wyoming, Utah, Nevada, California, Arizona, and New Mexico, in addition to the States infested in 1921.

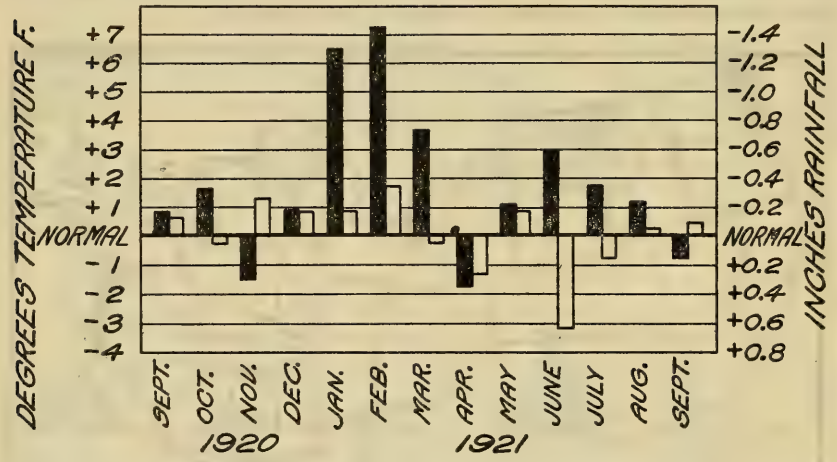

FIG. 8.—Monthly departures from normal temperature (solid black) and rainfall (white) from September, 1920, to September, 1921, inclusive, in the region infested by the pale western cutworm. (See also Table 4.)

In the region infested by this pest the temperatures were quite normal during the fall of 1920. During the winter of 1921 very mild weather prevailed, January and February averaging over 6° F. excess temperature. May was below normal, while the remainder of the spring and summer showed substantial excesses up to September, which showed a temperature deficiency of 2.9° F. (See Table 4 and Fig. 8.)

The rainfall over this region was generally below normal during the fall of 1920 and winter of 1920–21. Only slight excesses of precipitation occurred in April and June. (See Table 4 and Fig. 8.)

The map (Fig. 7) illustrates the area generally infested in 1921 (fine shading), the areas very seriously infested in 1921 (coarse shading), and previous records of occurrence (black dots).

TABLE 4.—*Monthly departures from normal temperature and rainfall from September, 1920, to September, 1921, inclusive, in the region infested by the pale western cutworm.*

DEPARTURES (IN DEGREES FAHRENHEIT) FROM NORMAL TEMPERATURE.

	1920.				1921.								
	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.
North Dakota	+2.6	+5.6	+1.4	+2.2	+11.2	+11.9	+2.6	−0.6	+1.2	+5.5	+3.9	+1.8	+0.6
Montana	+ .9	+1.6	−1.3	+2.5	+ 7.5	+ 8.9	+2.7	−1.1	+ .3	+3.6	+1.5	+1.8	−3.9
Wyoming	− .1	− .5	−3.7	+1.4	+ 3.8	+ 5.1	+4.3	−2.6	+1.0	+3.3	+1.3	+ .8	− .7
Colorado	− .9	− .7	−2.4	−2.8	+ 3.7	+ 3.6	+4.9	−2.3	+1.5	+ .5	+ .5	− .1	+1.1
Regional mean	+ .6	+1.5	−1.5	+ .8	+ 6.5	+ 7.4	+3.6	−1.6	+1.0	+3.2	+1.8	+1.1	− .7

DEPARTURES (IN INCHES) FROM NORMAL RAINFALL.

North Dakota	0.58	−0.48	−0.21	−0.22	−0.32	−0.10	+0.17	+0.43	−0.09	+0.55	+0.43	−0.36	+1.66
Montana	− .55	+ .03	− .51	− .17	− .31	− .30	+ .41	+ .13	− .32	+ .01	+ .00	− .63	− .28
Wyoming	− .33	+ .28	− .10	− .08	− .04	− .48	− .34	− .19	+ .06	+ .36	− .18	− .27	− .77
Colorado	− .27	+ .32	− .09	− .24	+ .05	− .47	− .10	+ .72	− .39	+1.52	+ .36	+1.17	− .97
Regional mean	− .14	+ .03	− .22	− .17	− .15	− .33	+ .03	+ .27	− .16	+ .61	+ .15	− .02	− .09

ALFALFA WEEVIL.

(*Phytonomus posticus* Gyll.)[3]

Since its original discovery in this country in the spring of 1904, the alfalfa weevil has continued to spread over the alfalfa-growing sections of the Great Basin and Rocky Mountain States and into the northern Pacific Coast States.

The original infestation in Utah has now spread to cover the entire northern two-thirds of the State, from Beaver County on the southwest to Duchesne and Summit Counties on the northeast, thence northwestward over the State, and into Idaho and Wyoming.

In Idaho the infestation is now known to be present in 28 counties, all in the southern part. Counties in which the weevil was discovered for the first time are Twin Falls, Owyhee, Gooding, Custer, Camas, Butte, and Blaine. The weevil was found in Owyhee County in the extreme northwestern corner, where it occurs sparsely in the Gem irrigation district. Weevils were abundant enough in the Arco, Mackey, and Carey localities of Butte, Custer, and Blaine Counties to be doing considerable damage. The infestation in Camas County is light, increasing from Fairfield to the alfalfa fields farthest east in the county. A single weevil was found in Gooding County in the Hagerman Valley near the town of Hagerman. In Twin Falls County the weevil was found to be present from about 3 miles west of Murtaugh to the easternmost alfalfa fields in the county; the infestation was light, however, and but little injury is anticipated in the immediate future. In Clark County the infestation has spread over all alfalfa sections. In the southeastern counties of Idaho the

[3] Reported by G. I. Reeves, of the Bureau of Entomology, and Claude Wakeland, of the Idaho Extension Service.

alfalfa weevil caused little injury this season; although climatic conditions may explain part of this phenomenon, it is evident that the parasite *Bathyplectes curculionis* Thoms. has been an important factor.

In Payette County the beetles were so numerous as absolutely to prevent any growth of the second crop for from four to six weeks, and in many places they turned their attention to garden truck after completely defoliating the alfalfa.

In Wyoming the weevil has been found in the southern part of Lincoln County, at several points in Uinta County, and at two points in Sweetwater County in the southwestern corner of the State.

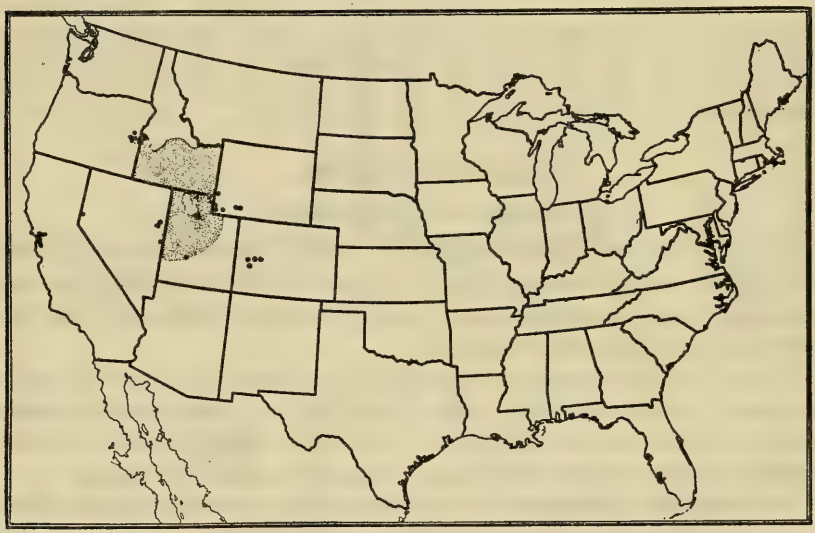

FIG. 9.—Geographical distribution of the alfalfa weevil in the United States in 1921: Shaded areas, generally infested; black dots, definite infested localities.

To the west, the Utah infestation has extended into Nevada, in the eastern third of White Pine County, and to the northwest this infestation has extended through Idaho into the northern part of Malheur County, Oreg.

Isolated outbreaks, probably the result of commercial transportation, have been discovered near the California State line in southern Washoe County, Nev., and in the east-central part of Colorado, in Delta, Montrose, and Gunnison Counties.

The weather conditions over the region infested by the alfalfa weevil show no excessive departures from the normal. The temperature during the fall of 1920 was slightly below normal, while the winter of 1920–21 was characteristically mild, the temperatures ranging between 3° and 4° F. above normal. April was generally cold,

while the remainder of the season was comparatively warmer. (See Table 5 and Fig. 10.)

The rainfall over this region was above normal during the fall and early winter. During the early spring slight droughts occurred during March. The remainder of the spring and summer were slightly above normal. September of 1921 showed a deficiency of about ½ inch. (See Table 5 and Fig. 10.)

Figure 9 illustrates the area known to be infested in 1921. The shaded area is generally infested and the black dots are definite localities where the pest has been collected.

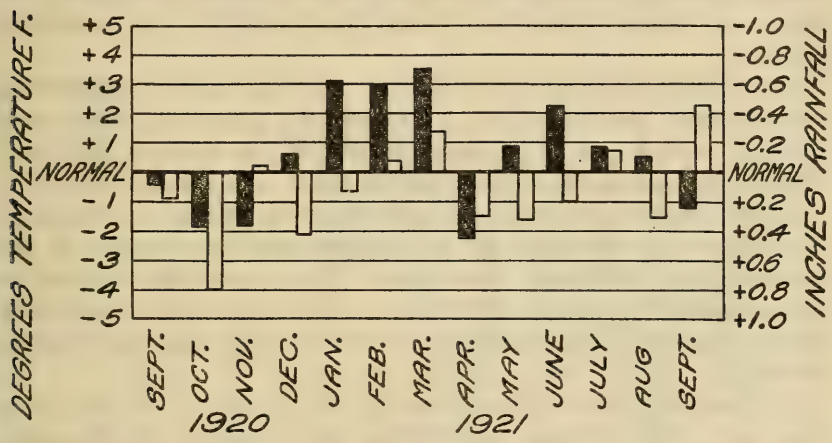

FIG. 10.—Monthly departures from normal temperature (solid black) and rainfall (white) from September, 1920, to September, 1921, inclusive, in the region infested by the alfalfa weevil. (See also Table 5.)

TABLE 5.—*Monthly departures from normal temperature and rainfall from September, 1920, to September, 1921, inclusive, in the region infested by the alfalfa weevil.*

DEPARTURES (IN DEGREES FAHRENHEIT) FROM NORMAL TEMPERATURE.

	1920				1921								
	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.
Wyoming	−0.1	−0.5	−3.7	+1.4	+3.8	+5.1	+4.3	−2.6	+1.0	+3.3	+1.3	+0.8	−0.7
Idaho	+.0	−2.1	−.7	+2.3	+3.4	+.9	+2.8	−2.9	+1.2	+2.8	+.6	+1.0	−3.9
Oregon	−.3	−2.1	−1.2	+2.0	+1.5	+1.9	+1.8	−1.4	+.3	+2.2	−1.0	−.1	−2.3
Utah	−.4	−2.2	−.7	−.2	+3.7	+2.9	+4.0	−3.1	+.8	+2.1	+1.2	−.3	−.8
Colorado	−.9	−.7	−2.4	−2.8	+3.7	+3.6	+4.9	−2.3	+1.5	+.5	+.5	−.1	+1.1
Nevada	−.1	−2.7	−1.1	+.4	+2.6	+2.8	+4.0	−1.8	+.0	+2.2	+1.6	+.4	−.4
Regional mean	−.3	−1.7	−1.6	+.5	+3.1	+2.9	+3.6	−2.3	+.8	+2.2	+.7	+.3	−1.2

DEPARTURES (IN INCHES) FROM NORMAL RAINFALL.

Wyoming	−0.33	+0.28	−0.10	−0.08	−0.04	−0.48	−0.34	−0.19	+0.06	+0.36	−0.18	−0.27	−0.77
Idaho	+.29	+1.02	+.19	+.83	+.18	+.00	−.15	+.38	+.77	−.40	−.43	+.05	−.30
Oregon	+1.83	+1.35	−.19	+1.90	+.74	+1.31	−.21	+.19	−.02	−.08	−.50	−.23	−.01
Utah	−.26	+1.77	−.12	+.23	+.05	−.39	−.33	+.71	+.40	−.22	+.01	+.95	−.69
Colorado	−.27	+.32	−.09	−.24	+.05	−.47	−.10	+.72	−.39	+1.52	+.36	+1.17	−.97
Nevada	−.18	+.24	+.04	−.08	−.22	−.39	−.56	−.09	+1.12	−.05	−.16	+.09	−.22
Regional mean	+.18	+.83	−.05	+.42	+.12	−.07	−.28	+.28	+.32	+.18	−.15	+.29	−.49

SORGHUM WEBWORM.

(*Celama sorghiella* Riley.)

A very unusual outbreak of the sorghum webworm occurred in southern Missouri, southeastern Kansas, and western Arkansas. No reports were received from northwestern Oklahoma, but the pest undoubtedly occurred at least in the northwestern corner.

Celama sorghiella was described by Riley, from Citronelle, Mobile County, Ala., in 1882. Records of its occurrence have been made from south-central Texas, northward and eastward through southeastern Kansas, central Missouri, southern Indiana, northern Virginia, and central Maryland, thence southward to and including Florida.

In Arkansas the sorghum webworm outbreak was the outstanding entomological feature of the year, and the grain sorghums were damaged to the extent of from 25 to 100 per cent of the crop. Sixteen counties in the central and western part were infested.

In Missouri the outbreak was most serious in the strip of territory extending from the vicinity of Clinton south to Neosho or the Arkansas and Oklahoma State lines. Kafir corn was reported as being damaged to the extent of 50 per cent of the crop in some cases. Sixteen counties in the southern half of the State were reported as infested.

In Kansas this insect was reported for the first time attacking kafir corn. The outbreak was confined to five counties in the southeastern part. In some instances plantings were a total loss.

TABLE 6.—*Amount of sorghum and kafir-corn forage harvested in 1919 in five counties in Kansas infested with the sorghum webworm, and the amount and value of sorghum seed and kafir seed harvested.*

County.	Sorghum, kafir, etc., forage.[1]	Sorghum seed, 1919.		Kafir seed, 1919.	
		Quantity.	Value.	Quantity.	Value.
	Tons.	*Bushels.*		*Bushels.*	
Bourbon	15,016	6,698	$10,181	146,412	$187,407
Cherokee	12,795	5,552	7,772	81,054	102,938
Chautauqua	21,999	54,726	75,521	194,005	248,390
Greenwood	64,742	6,448	8,704	355,878	480,335
Labette	7,109	1,640	2,460	110,325	165,487
Total	121,661	75,064	104,638	887,674	1,184,557

[1] From 1920 census.
[2] From report of Kansas State Board of Agriculture.

	Bushels of seed.
Missouri	405,000
Arkansas	302,000
Kansas	963,000
Total	1,670,000

The relative importance of this pest can be estimated approximately from the available data on the quantity and value of this

crop in the infested territory during the season of 1919. Table 6 indicates the amount of sorghum and kafir corn forage harvested in the five counties in Kansas during the season 1919 according to the Fourteenth Census, and the number of bushels of sorghum seed and kafir seed harvested from the same counties during 1919, and the values of each, according to the figures given in the Twenty-second Biennial Report of the State Board of Agriculture of Kansas.

According to these figures it will be seen that in the five infested counties in Kansas over 121,000 tons of sorghum and kafir forage were harvested in 1919, while approximately 963,000 bushels of seed were harvested, valued at $1,289,000. By comparing these figures with the census figures for Missouri and Arkansas, it is seen that

FIG. 11.—Geographical distribution of the sorghum webworm in the United States: Shaded area, seriously infested in 1921; black dots, localities from literature.

over 1,500,000 bushels of this seed were produced in the infested counties in the three States during 1919. The lowest estimated damage in this territory amounted to 25 per cent of the seed.

The map (Fig. 11) indicates the area infested this year (shaded) and previous records of the occurrence of this insect (black dots).

The temperature in the region infested by the sorghum webworm was very uniform, the graphs of the three States showing marked similarity. The temperature throughout the entire season was characteristically above normal, the low temperatures of November being the only exception. The winter was extremely mild, ranging about 4° or 5° F. above normal, while the spring and summer were slightly above normal. (See Fig. 12 and Table 7.)

The rainfall in this region was also quite uniform in the three States, rainy periods occurring in March and April and decided

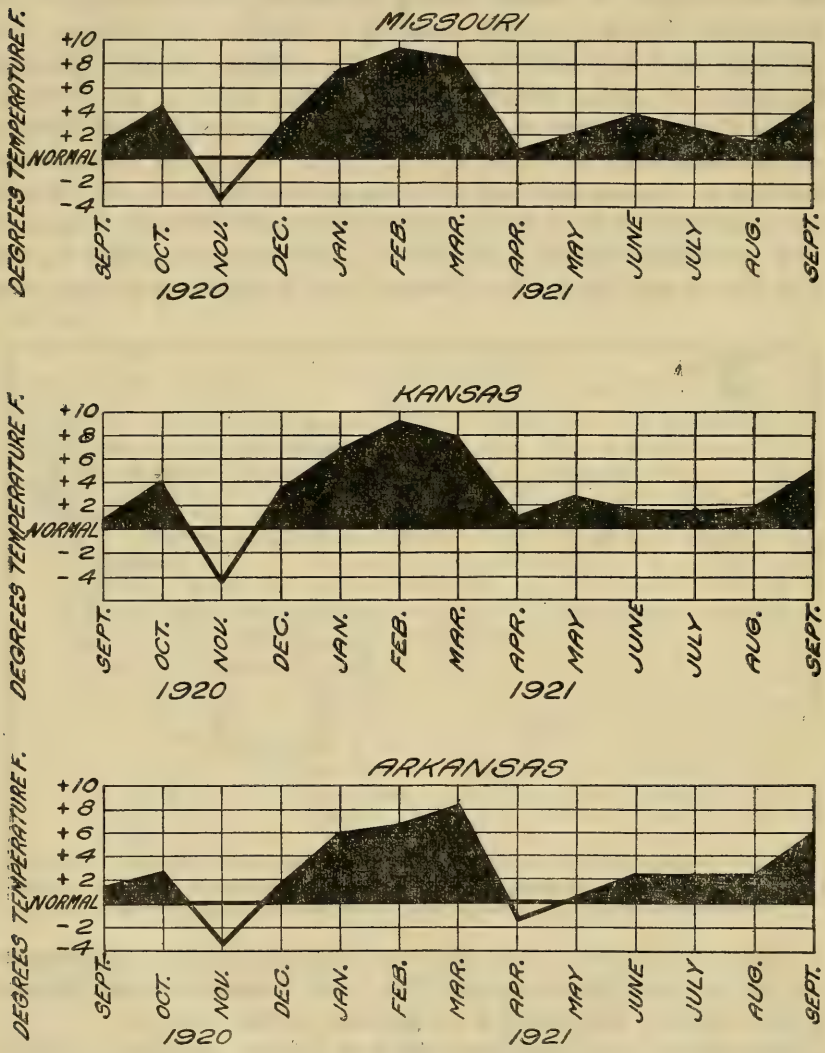

FIG. 12.—Monthly departures from normal temperature for the fall of 1920, the winter of 1920–21, and the growing season of 1921 in the region infested by the sorghum webworm during 1921. (See also Table 7.)

droughts in January, February, May, and July. (See Fig. 13 and Table 7.)

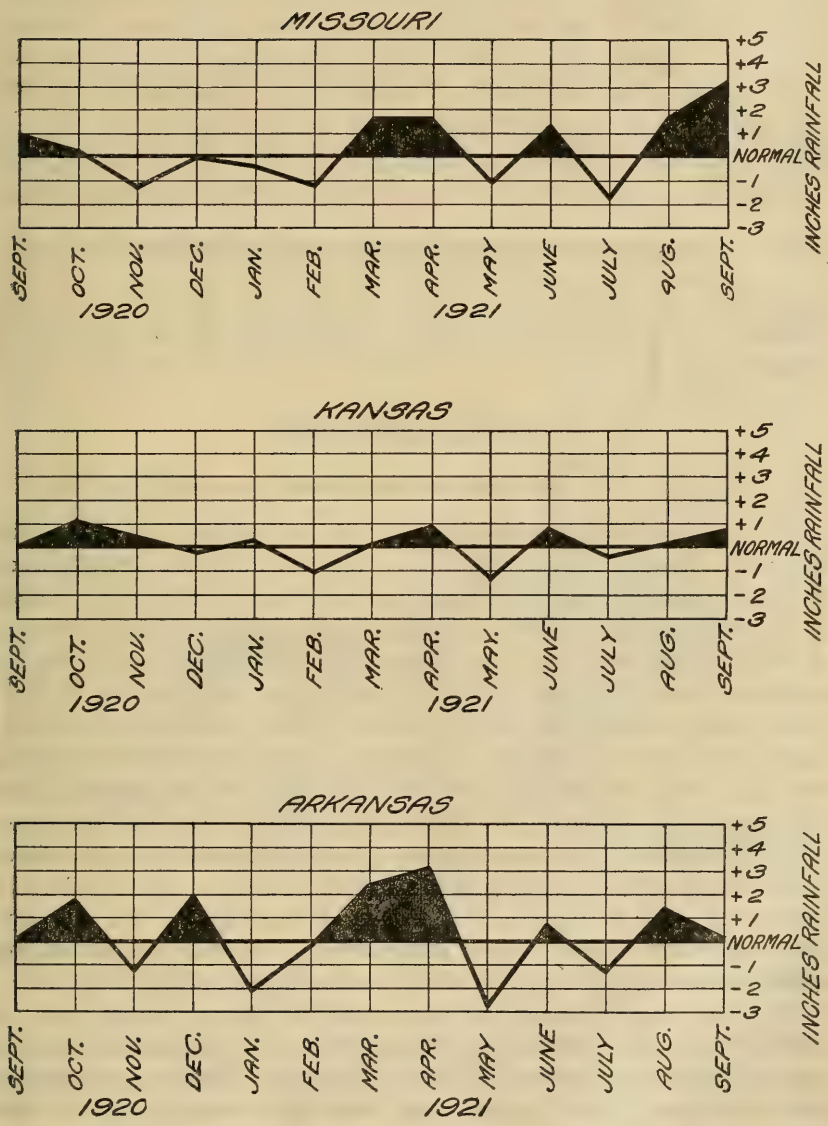

FIG. 13.—Monthly departures from normal rainfall for the fall of 1920, the winter of 1920–21, and the growing season of 1921 in the region infested by the sorghum webworm during 1921. (See also Table 7.)

TABLE 7.—*Monthly departures from normal temperature and rainfall for the fall of 1920, the winter of 1920–21, and the growing season of 1921 in the region infested by the sorghum webworm during 1921.*

DEPARTURES (IN DEGREES FAHRENHEIT) FROM NORMAL TEMPERATURE.

	1920				1921								
	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.
Missouri	+1.4	+4.3	−3.5	+2.6	+7.2	+9.1	+8.5	+0.9	+2.0	+3.4	+2.9	+0.8	+4.7
Kansas	+.6	+3.8	−4.4	+3.2	+6.9	+9.0	+7.3	+.9	+2.4	+1.6	+1.1	+1.4	+4.6
Arkansas	+1.2	+2.2	−3.9	+1.2	+5.7	+6.3	+8.3	−1.1	+.7	+2.1	+2.2	+2.4	+6.0
Regional mean	+1.0	+3.4	−3.9	+2.3	+6.6	+8.1	+8.0	+.2	+1.7	+2.3	+2.0	+1.5	+5.1

DEPARTURES (IN INCHES) FROM NORMAL RAINFALL.

Missouri	+0.92	+0.25	−1.09	−0.22	−0.38	−1.33	+1.68	+1.52	−1.20	+1.15	−1.77	+1.63	+3.15
Kansas	+.22	+1.04	+.19	−.07	+.37	−1.01	+.66	+.72	−1.31	+.81	−.37	+.26	+.58
Arkansas	+.06	+1.68	−1.47	+1.92	−2.08	−.18	+2.10	+3.02	−2.83	+.60	−1.43	+1.40	+.03
Regional mean	+.40	+.99	−.79	+.54	−.69	−.84	+1.28	+1.75	−1.78	+.85	−1.19	+1.09	+1.25

EUROPEAN CORN BORER.

(*Pyrausta nubilalis* Hübn.)[4]

The outstanding developments in the corn-borer situation for 1921 were, first, the serious injury to field corn and the development of a much greater area of infestation than was believed to be present in the Province of Ontario, Canada; second, the discovery by Bureau of Entomology scouts of the presence of the insect along the entire southern shore of Lake Erie from the extreme western line of New York State through Pennsylvania and Ohio to southeastern Michigan, just south of the city of Detroit. The latter infestation is a very mild and uniform one and, so far as has been ascertained, does not extend far inland. No commercial injury whatever has been done in this area as yet; nevertheless, its establishment there becomes of great importance, as indicating that this insect is in a position to invade the area of most intensive corn production in this country. The conditions in the various other areas of infestation prevailing at the beginning of the spring of 1922 are as follows (Fig. 14):

The corn borer is known to be present throughout a total area of 7,696 square miles within the United States, as compared with an area of 7,690 square miles in Ontario, Canada. The area of infestation in eastern New England comprises 2,670 square miles. The spread there during the past year has been comparatively small, and in every case is contiguous to the area of infestation as known in 1920. A very small incipient infestation discovered during the summer of 1920 in the township of Eliot, Me., was cleaned up and

[4] Reported by W. R. Walton, Bureau of Entomology.

did not appear during the summer of 1921, but as the southwestern corner of that State is in the direct path of the natural spread of the insect, it may be expected that this territory will become infested by natural means in the immediate future. The infestation prevailing in corn in the most intensely infested part of the old area of infestation in Massachusetts is practically unchanged. On the other hand, a considerably higher degree of infestation has occurred in the case of other cultivated crops, including especially vegetables and flowers. It is estimated that the loss to corn in this heavily infested area as a direct result of the injury of the insect ranged from 8 to

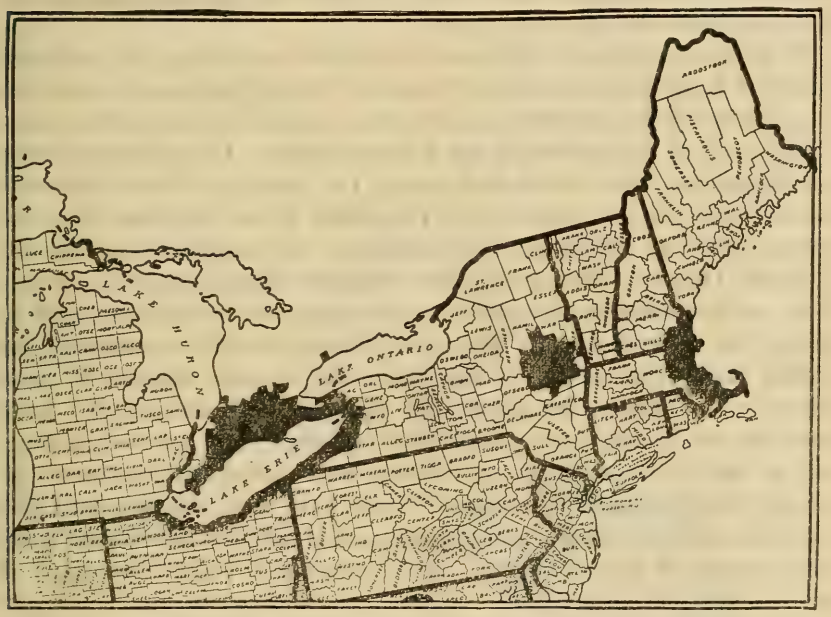

FIG. 14.—Geographical distribution of the European corn borer in the United States and Canada in 1921, shown by black areas.

20 per cent of the total value of the crop. Outside of this heavily infested area and in some fields within it, little or no commercial damage has as yet occurred to the ears of either sweet or field corn.

In the eastern New York area in the vicinity of Schenectady and Albany, the infested area comprises 2,203 square miles. The commercial injury here has as yet been almost negligible. Not more than 1 per cent of the ears of corn from infested fields were discarded as unmarketable on account of corn-borer injury. The degree of infestation in sweet corn in this area was slightly greater than in 1920. In western New York, in the vicinity of Buffalo and Dunkirk, an area which is now continuous with the infested areas in

Pennsylvania, Ohio, and Michigan, the total infestation comprises 1,634 square miles in New York, 347 square miles in Pennsylvania, 757 square miles in Ohio, and 85 square miles in Michigan. The commercial loss to the corn crop in the western New York area as yet has been comparatively slight. The average infestation of field corn here was slightly greater than in the preceding year. Of the most heavily infested fields, 17 showed an average stalk infestation of 32 per cent, and an average of two borers per infested stalk.

Six fields of sweet corn representing maximum infestation in this area showed an average of three borers per infested stalk, and a stalk infestation averaging 33 per cent. Commercial damage throughout the area, however, was very slight.

With the exception of the newly infested area along the southern shore of Lake Erie, the rate of natural spread previously observed, i. e., about 6 miles per year, has not been exceeded in any of the principal areas of infestation in the United States. It is suspected that the slight uniform infestation along the shore of Lake Erie was caused by a forced migration of the moths across the lake from the intense area of infestation prevailing in the neighborhood of St. Thomas, Ontario. Records of the Weather Bureau observation stations on the southern shore of the lake show that for the first time in five or six years the winds prevailing during the flight season of the moths blew from north or northeast for several days at a time. There is, of course, the possibility that this infestation may have been caused by the drift of infested material from across the lake, but as yet no traces of the presence of such material have been discovered on the southern shore of Lake Erie, and, furthermore, the uniform character of this mild infestation is believed to indicate some other means of dissemination. In an attempt to solve this phase of the problem the bureau has requested the permission of the Lighthouse Service to station observers during the flight season of the moths at several of the powerful lights maintained on the southern shore in order to ascertain whether corn-borer moths are attracted by these lights.

During April, 1922, the Bureau of Entomology established a field laboratory at Sandusky, Ohio, where a small corps of observers was stationed for the purpose of observing the insect and its progress of infestation. Additional plans for the combat of the insect include the maintenance of the quarantines throughout the infested areas, the scouting of all suspected territory, and the issuance of a new Farmers' Bulletin giving the practical results of investigations carried on by the bureau during the past three years. This will be followed by a professional paper containing all important technical details of the work.

CAMPHOR SCALE.

(*Pseudaonidia duplex* Ckll.)[5]

The camphor scale was first discovered in the United States at New Orleans in August, 1920, by E. R. Barber of the Bureau of Entomology. At that time it appeared to be infesting only the plants within a few blocks of the M. Cook nursery. It seems possible that this insect had been introduced on a Japanese rose through a Los Angeles nursery. In April, 1921, the infestation was surveyed and was then found to cover 27 city blocks. In early May a hurricane blew the young crawlers long distances in all directions, and in one case they were found, after the storm, nearly 2 miles from the center of infestation. During the summer the city of New Orleans and the State of Louisiana appropriated $33,000 in an effort to control the spread of this pest, which was threatening the camphor trees, one of the most beautiful landscape features of New Orleans. With these funds an effort was made to hold the pest to an area of about 4 square miles, and during this campaign more than 600 isolated infestations in various parts of the city were cleaned up.

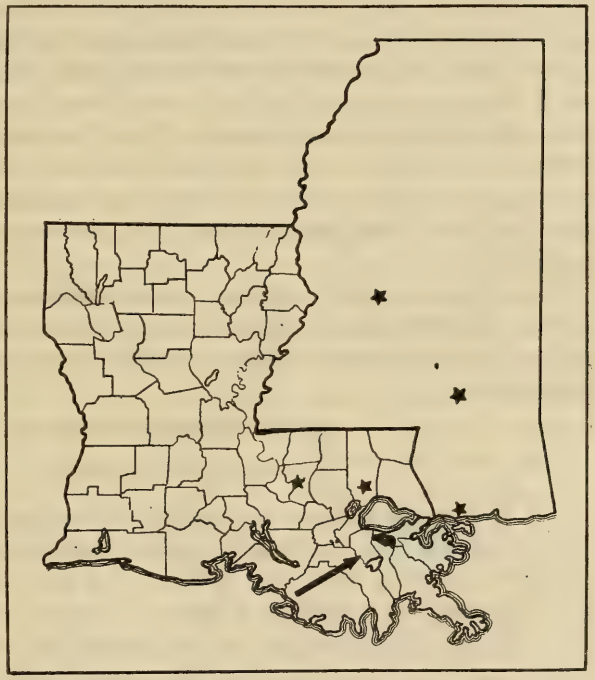

FIG. 15.—Geographical distribution of the camphor scale in the United States in 1921: The black area indicates the New Orleans infestation; the stars indicate areas where the scale has been found and eradicated.

On July 18, 1921, this insect was discovered for the first time in Mississippi at Hattiesburg on plants that were traced to shipments from New Orleans, made two years previously. The State plant board immediately took this outbreak in hand and condemned and burned all infested plants. On August 13, another infestation was located in Mississippi at Jackson, this also being traced to material

[5] From reports of E. R. Barber, R. W. Harned, and T. H. Jones.

shipped from New Orleans, and similar radical methods for the eradication of the pest were undertaken here.

The first record of this pest in Louisiana, outside of the city of New Orleans, was made on September 23, 1921, when complaint was made of an outbreak in Victory Park, Baton Rouge, on *Camellia japonica*. The plants had been set out in the park about a year before and came from New Orleans. Another record of this pest in Louisiana was made on December 4, when specimens were sent to the agricultural experiment station from Hammond.

During November two new infested localities were discovered in Mississippi, one at Pass Christian and the other at Biloxi.

In January, 1922, a most discouraging discovery was made. Up to this time the successful eradication work in Mississippi and the work being carried on in the city of New Orleans gave hope that this pest might be exterminated. Then the pest was discovered infesting the large swamp area north of the city of New Orleans, covering a territory of about 10 square miles, making it very improbable that it will ever be destroyed. Its present distribution is shown in Figure 15.

The camphor scale has been found infesting a large variety of plants. Upward of 150 different species have already been recorded as food plants, some of them casually, but a large number very intensively.

MEXICAN BEAN BEETLE.

(*Epilachna corrupta* Muls.)[6]

The Mexican bean beetle was originally confined to the region lying west of central Texas and south of the northern border of Colorado, including Arizona and New Mexico. In 1920 it was discovered in the Birmingham region in Alabama. Survey work was instituted that year and the distribution was found to cover all of Jefferson, Shelby, and St. Clair Counties, the greater part of Etowah, Dekalb, Blount, and Bibb Counties, the eastern half of Tuscaloosa County, and the adjacent parts of Walker, Cullman, Marshall, Cherokee, Calhoun, Talladega, and Chilton Counties.

Federal quarantine was instituted on May 1, 1921, for the infested area and survey work carried on through the season of 1921. By July 26, 1921, the infested area was found to be so extensive that practical quarantine was impossible and the quarantine was raised. At the present time this beetle is known to infest the northern half of Alabama, the northern fourth of Georgia, the eastern third of Mississippi, and the extreme western corners of North Carolina and South Carolina.

[6] From reports of J. E. Graf, N. F. Howard, and others, Bureau of Entomology.

The area in Alabama is now bounded on the west by a line extending through the northwestern corner of Limestone County, through the center of Colbert County to the eastern border of Pickens County, thence southeastward to the northern border of Hale County, and eastward along the northern boundary of Perry County, extending thence southward into the northern arm of Dallas County, and eastward through southern Chilton and Coosa Counties, northern Tallapoosa County, and the southern border of Randolph County.

The infested area in Georgia extends southward to a line starting at the southern border of Heard County, extending southeastward into the northern corner of Troup County, thence northward through the eastern border of Carroll County and eastward across the center of Cobb County and the northern part of DeKalb County to the northern border of Wilkes County, thence in a northwesterly direction through the center of Madison and Banks Counties and northeastward to the center of Stevens County.

In Tennessee the infested area is bounded by a line extending from the southeastern corner of Giles County, northeastward through the center of Lincoln and Moore Counties, and northward across Coffee and Cannon Counties, and eastward to the northwestern corner of White County, thence across the southeastern corner of Putnam and Overton Counties, along the western boundary of Fentress County and the northern part of Scott County, and into Kentucky. It again returns into the State in Campbell County and runs eastward through Union and Grainger Counties, to the easternmost point in Hamblen County; the line then extends southwestward along the southern border of Hamblen County across the center of Jefferson County and the eastern quarter of Sevier County to the southeastern corner of the State.

The northmost part of the Tennessee infestation is continuous with a very small area in southern McCreary and Whitley Counties, Ky.

The area in South Carolina extends across Oconee and Pickens Counties and into Greenville County, and the area in North Carolina includes the greater part of Cherokee and Clay Counties.

The shaded area on the map (Fig. 16) is the area in the East known to have been infested in 1921. The solid-colored area was known to have been infested in 1920. The dots indicate localities from which this insect has been recorded in literature.

Table 8 and Figure 17 contain data on the departures from the normal temperature and rainfall in 1920–21 in the region infested by the Mexican bean beetle.

FIG. 16.—Geographical distribution of the Mexican bean beetle in the United States: Solid-colored area, known to have been infested in 1920; shaded area, known to have been infested in 1921; black dots, localities from literature.

TABLE 8.—*Monthly departures from normal temperature and rainfall from September, 1920, to September, 1921, inclusive, in the region infested by the Mexican bean beetle.*

DEPARTURES (IN DEGREES FAHRENHEIT) FROM NORMAL TEMPERATURE.

	1920				1921								
	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.
Alabama	+1.7	+0.4	−2.9	−1.0	+4.1	+3.4	+7.7	−0.8	−0.7	+2.9	+1.5	+0.9	+6.2
Georgia	+1.5	−.2	−1.6	+.2	+3.1	+3.9	+7.7	+.2	−1.9	+2.0	−.2	−.2	+6.2
Tennessee	+1.3	+2.1	−2.4	+1.5	+4.3	+5.1	+10.0	+.9	−.3	+3.8	+2.9	+.4	+6.6
South Carolina	+1.5	+.5	−1.5	−.2	+1.3	+2.4	+7.5	+1.0	−3.1	+1.7	−.2	−.6	+5.8
North Carolina	+1.9	+1.2	−.1	+1.3	+1.4	+3.2	+8.9	+2.6	−2.8	+1.8	+1.1	−.3	+6.6
Regional mean	+1.6	+.8	−1.7	+.4	+2.8	+3.6	+8.3	+.8	−1.7	+2.4	+1.0	+.0	+6.3

DEPARTURES (IN INCHES) FROM NORMAL RAINFALL.

Alabama	−0.71	−1.54	+0.07	+2.92	−1.65	+0.04	−0.91	+2.05	−1.96	−2.18	−0.34	−0.48	−0.76
Georgia	+.05	−1.87	+1.12	+1.31	−.96	−.54	−3.21	−.22	+.72	−2.00	+1.13	−.95	−1.44
Tennessee	+.83	−1.60	−.72	+.31	−1.56	+1.21	+.09	+.46	−1.78	−1.66	+.15	+1.50	+1.33
South Carolina	+1.48	−2.29	+1.34	+.60	+.39	+.37	−1.58	−.48	+1.79	−2.08	+1.50	−1.94	−.51
North Carolina	+.95	−2.54	+2.33	+1.93	+.45	+.22	−1.50	+.51	+.41	−2.08	−.57	−2.45	−1.03
Regional mean	+.52	−1.96	+.82	+1.41	−.66	+.26	−1.42	+.46	−.16	−2.00	+.37	−1.26	−.48

SWEET-POTATO WEEVIL.

(*Cylas formicarius* Fab.)[7]

The sweet-potato weevil is known to occur in all of the Gulf States and the southern part of Georgia. East of the Mississippi River the

[7] From report submitted by F. H. Chittenden and others, Bureau of Entomology.

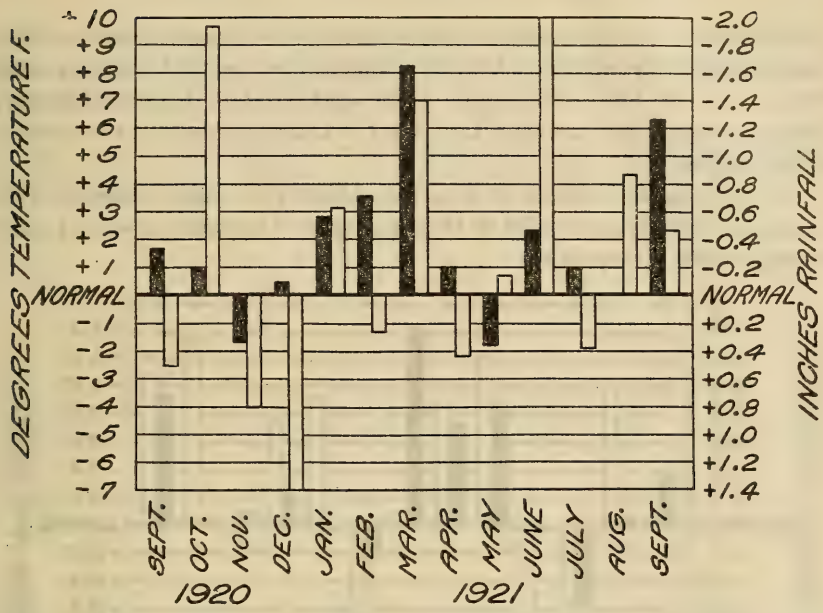

FIG. 17.—Monthly departures from normal temperature (solid black) and rainfall (white) from September, 1920, to September, 1921, inclusive, in the region infested by the Mexican bean beetle. (See also Table 8.)

outbreaks have been confined for the most part to the coastal region. In Louisiana and Texas, however, the area infested is much more extensive, covering the greater part of these States. (See Fig. 18.)

In Florida eradication work is being attempted at two points, one in Baker County and the other at Arcadia in De Soto County. The

FIG. 18.—Geographical distribution of the sweet potato weevil in the United States in 1921, shown by black areas.

pest is known to be present throughout the greater part of the coastal region from Pasco County south along the west coast around the end of the Peninsula, and up the east coast to Volusia County. On the coastal line, however, the insect is mainly infesting the seaside morning-glory.

In Georgia an outbreak in Charlton County is under control. The work has been so successful in this county that no weevils were found during the fall inspection.

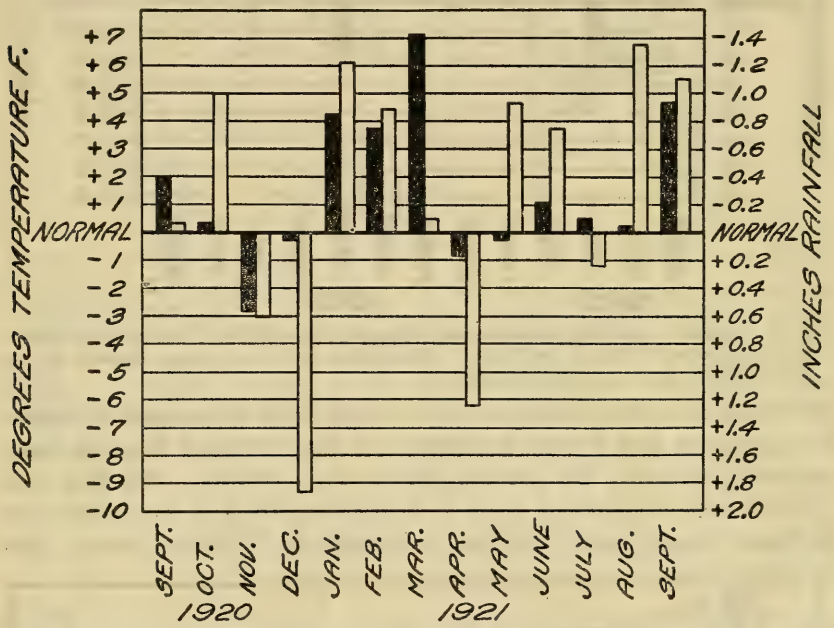

FIG. 19.—Monthly departures from normal temperature (solid black) and rainfall (white) from September, 1920, to September, 1921, inclusive, in the region infested by the sweet-potato weevil. (See also Table 9.)

In Alabama the original infestation has probably been eradicated, but the fall inspection disclosed a new though small infestation along the coast in Mobile County.

In Mississippi an attempt is being made to eradicate the weevil from the four coast counties. Substantial progress has been made in Pearl River, Hancock, and Harrison Counties, but the work is being delayed in Jackson County on account of inadequate force. No eradication work is being attempted west of the Mississippi River, and in this area the weevil is slowly extending its range northward. At the present time it has been reported in the vicinity of Shreveport, La., as well as in two counties in southern Oklahoma. Should the latter report be verified it will mark the first infestation north of the Red River.

Data on the departures from normal temperature and rainfall in 1920–21 in the region infested by the sweet-potato weevil are given in Figure 19 and in Table 9.

TABLE 9.—*Monthly departures from normal temperature and rainfall from September, 1920, to September, 1921, inclusive, in the region infested by the sweet-potato weevil.*

DEPARTURES (IN DEGREES FAHRENHEIT) FROM NORMAL TEMPERATURE.

	1920				1921								
	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.
Texas	+1.8	+0.5	−2.9	+0.5	+5.7	+3.6	+5.6	−1.8	+0.6	−0.8	+0.0	+1.7	+4.0
Louisiana	+2.5	+.5	−4.2	+.4	+5.8	+4.3	+7.8	−1.2	−.8	+.2	+.8	+1.7	+4.2
Mississippi	+2.6	+1.0	−4.2	−.1	+5.1	+4.2	+8.4	−1.3	−.4	+1.9	+1.7	+1.9	+5.9
Alabama	+1.7	+.4	−2.9	−1.0	+4.1	+3.4	+7.7	−.8	−.7	+2.9	+1.5	+.9	+6.2
Georgia	+1.5	−.2	−1.6	+.2	+3.1	+3.9	+7.7	+.2	−1.9	+2.0	−.2	−.2	+6.2
Florida	+.6	−1.8	−1.1	−.8	+2.0	+3.0	+5.4	+.4	+2.2	+.7	−.7	+.3	+2.7
Regional mean	+1.8	+.1	−2.8	−.1	+4.3	+3.7	+7.1	−.7	−.1	+1.1	+.5	+1.0	+4.8

DEPARTURES (IN INCHES) FROM NORMAL RAINFALL.

Texas	−0.65	+1.20	+0.27	−0.66	+0.04	−0.29	+0.82	+0.46	−1.74	+3.39	−0.42	−1.60	+1.20
Louisiana	−.02	+.20	+.55	+4.10	−1.27	−2.28	+1.35	+1.77	−1.54	+.55	+.35	−2.08	−.74
Mississippi	−.19	−1.21	−.02	+3.11	−2.00	−.66	+2.64	+4.09	−3.00	−1.43	−.51	−.66	−.33
Alabama	−.71	−1.54	+.07	+2.92	−1.65	+.04	−.94	+2.05	−1.96	−2.18	−.34	+.48	+.76
Georgia	+.05	−1.87	+1.12	+1.31	−.96	−.54	−3.21	−.22	+.72	−2.00	+1.13	−.95	−1.44
Florida	+1.32	−2.75	+1.83	+.63	−1.49	−1.56	−1.16	−.58	+1.95	−2.74	+1.43	−2.32	−4.53
Regional mean	−.03	−.99	+.63	+1.90	−1.22	−1.04	−.08	+1.26	−.93	−.73	+.25	−1.02	−.86

POTATO LEAFHOPPER.

(*Empoasca mali* LeB.)

During the year the potato leafhopper was seriously destructive over a large part of the commercial potato-growing region of the United States, and Mr. Gibson, Dominion entomologist, reports it as the most destructive potato pest during this season in Canada. The association of this insect with potato tipburn ("hopperburn") has stimulated interest in the depredations of this pest. Part of the distribution areas on the accompanying map (Fig. 20) were obtained from the survey reports of the plant disease survey, Bureau of Plant Industry.

The most serious infestations were in the North-Central and East-Central States. In Illinois the leafhopper caused considerable loss to potatoes over the entire State, except where these were protected by Bordeaux spray. Serious injuries were also reported from the northern half of Indiana and the central part of Ohio. The insect was also seriously abundant throughout the entire potato growing sections of Minnesota, Wisconsin, and Michigan.

In North Dakota outbreaks were recorded from the southeastern part of the State, extending from Grand Forks County to Dickey

County and eastward. In South Dakota the infested region was continuous with that in North Dakota, extending westward to the middle of McPherson County through Hand County to Charles Mix County. By the middle of July in South Dakota many of the potato fields were practically dead as a result of "hopperburn."

In Iowa this insect was recorded as being one of the principal causes of low yields of potatoes. At Oelwein, in Fayette County, the crop was almost a complete failure.

In the New England and Middle Atlantic States quite serious infestations were recorded from eastern Vermont and western New Hampshire, along the Connecticut River Valley, the infestation being continuous with that extending through central Massachusetts

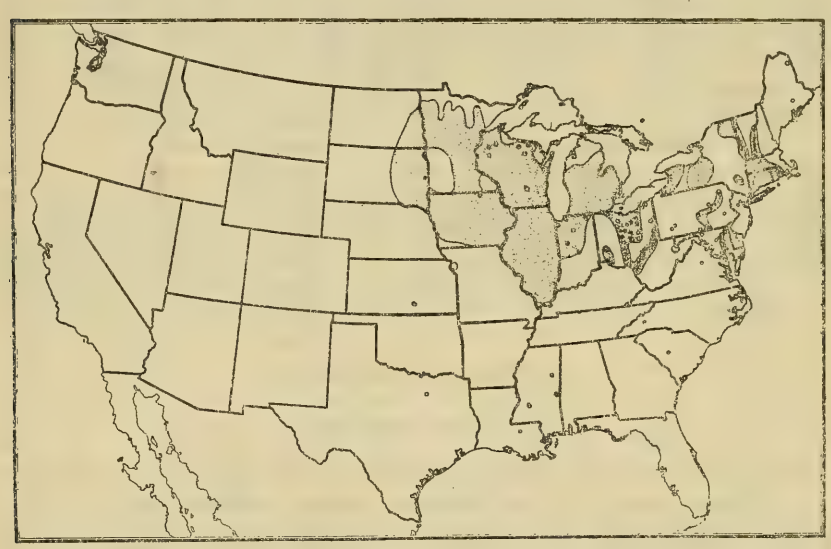

FIG. 20.—Geographical distribution of the potato leafhopper in destructive numbers in the United States in 1921, shown by shaded areas. Dots are localities of very severe infestation; circles, localities from literature.

and the greater part of Connecticut and Rhode Island. A similar infestation extended along the western side of Vermont, running parallel with the Hudson River Valley infestations in New York.

In New York serious outbreaks were recorded from central and western sections, Long Island, and Ulster County, very severe infestations being recorded from Chautauqua, Genesee, Wayne, Steuben, Onondaga, Ulster, and Suffolk Counties.

In Pennsylvania serious outbreaks were recorded up the Susquehanna River Valley.

West Virginia recorded an outbreak in the Ohio River Valley continuous with that in Ohio, and also recorded that this insect was much more abundant than usual in Tucker County.

Isolated reports were received from Buncombe County, N. C., Buchanan County, Mo., and Oktibbeha, Lauderdale, and Copiah Counties, Miss.

The map in Figure 20 indicates, by shading, the area of serious infestation. The black dots indicate reports of definite localities where exceptionally serious damage was sustained during 1921, while the circles indicate localities from which reports of outbreaks have been received in previous years.

SEED-CORN MAGGOT.

(*Hylemyia cilicrura* Rond.)

During the past season a rather remarkable outbreak of the seed-corn maggot attacking the seed pieces of early planted potatoes occurred along the Atlantic seaboard.

FIG. 21.—Map indicating sequence of reports of destructive abundance of the seed-corn maggot in the United States in 1921.

Early in April the first report was received from North Carolina, the outbreak being reported as both severe and extremely unusual, 50 per cent of the early planted crop in the Beaufort district having been destroyed, many of the fields so seriously damaged as to necessitate replanting, and others abandoned. The infested area included the region bounded by a line extending along the northern border of Dare and Tyrrell Counties, across the center of Bertie and southeastern corner of Halifax Counties, thence southward across Edgecombe and Wilson Counties, the western third of Greene County, the middle of Lenoir County and eastward across the upper third

of Jones County, the south shore of Pamlico County, and the northern part of Carteret County.

This was followed about the middle of April by reports coming in from Norfolk and the eastern-shore districts of Virginia. In this State both the entomologist and the plant pathologist were inclined to believe that the seed-corn maggot was of secondary importance and that the chief damage was being occasioned by a Fusarium disease.

By April 21 serious reports were coming in from the eastern shore of Maryland and the southern half of New Jersey, where by actual count 10 per cent of the seed pieces were damaged to such an extent that the plants failed to develop properly. By May 1 this outbreak had become so serious that 20 per cent of the hills were missing in the infested fields. In this State it also did serious damage to pea and bean seeds and lettuce plants.

Early in May potato seed pieces were being attacked on Long Island, but here the outbreak was not at all serious.

About May 10, reports were received from Massachusetts that this insect was seriously attacking the onion plantings in the Connecticut River Valley, some fields suffering 25 per cent damage, and the last report of the season was received from Maine on June 16, where this insect was recorded as damaging the underground stems of beans.

The early potato planting season along the Atlantic coast was characterized by hot and dry weather. Germination was slow and conditions were possibly advantageous for the development of certain fungous diseases which, undoubtedly, were associated with the depredations of, if not responsible for the damage attributed to the seed-corn maggot.

One of the most interesting features of the survey reports on this insect were the independent reports from Maryland, Massachusetts, and New Jersey, that infestations were far worse on fields where meat scrap or fish scrap fertilizers were used. These reports indicate that organic fertilizers of this class are attractive to the adult seed-corn maggots.

Figure 21 indicates the sequence of reports received relative to the destructive abundance of this pest along the Atlantic seaboard in 1921.

The correlation of the weather conditions with insect outbreaks was most forcefully illustrated during the past season by the very unusual outbreak of this pest. The weather over the infested region was characterized during the late winter and early spring by very decided excesses of temperatures, January showing an excess of nearly 3° F, February of 4½°, March of 10°, and April of 5½°. This was accompanied by marked deficiencies in rainfall during

these months. In May throughout this region the weather suddenly changed, this month showing a deficiency in temperature and an excess in rainfall. The warm, dry weather of the early spring facilitated seeding and the greater part of the crop was planted early. The continued warm, dry weather interfered with germination and was very favorable for the heavy infestation of the seed pieces by this insect. The cold, wet weather of May started germination and terminated the erstwhile serious infestation of seed-corn maggots. Later plantings were not infested.

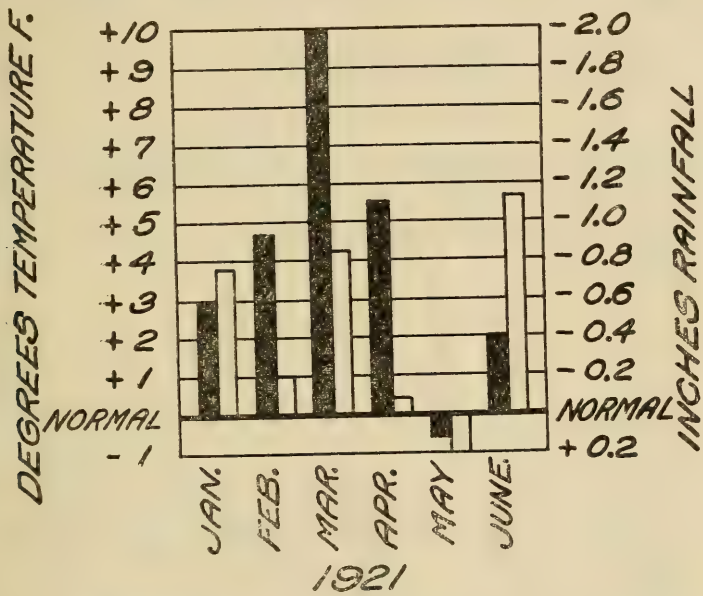

FIG. 22.—Monthly departures from normal temperature (solid black) and rainfall (white) in the region infested by the seed-corn maggot, January to June, inclusive, 1921. (See also Table 10.)

Figure 22 and Table 10 give data on departures from normal temperature and rainfall in 1921 in the region infested by the seed-corn maggot.

TABLE 10.—*Monthly departures from normal temperature and rainfall in the region infested by the seed-corn maggot, January to June, inclusive, 1921.*

DEPARTURES (IN DEGREES FAHRENHEIT) FROM NORMAL TEMPERATURE IN 1921.

	January.	February.	March.	April.	May.	June.
New England	+3.4	+3.5	+9.4	+5.6	+0.8	+0.0
New York	+2.7	+5.4	+9.8	+7.6	+1.6	+1.6
Pennsylvania	+3.1	+5.5	+10.8	+6.7	−.6	+2.7
New Jersey	+3.0	+4.4	+10.3	+6.8	−.2	+1.8
West Virginia	+3.3	+5.4	+10.0	+4.1	−.7	+3.2
Maryland and Delaware	+3.1	+5.0	+11.3	+5.5	−1.6	+2.2
Virginia	+2.2	+4.6	+10.6	+4.7	−2.7	+1.5
North Carolina	+1.4	+3.2	+8.9	+2.6	−2.8	+1.8
Regional mean	+2.7	+4.6	+10.1	+5.4	−.7	+1.8

TABLE 10.—*Monthly departures from normal temperature and rainfall in the region infested by the seed-corn maggot, January to June, inclusive, 1921*—Continued.

DEPARTURES (IN INCHES) FROM NORMAL RAINFALL IN 1921.

New England	−1.48	−0.55	−0.64	+0.77	−0.76	−0.53
New York	−1.29	−.26	+.30	+.45	−1.41	−.83
Pennsylvania	−.66	−.26	−.19	−.23	+.26	−1.18
New Jersey	−1.03	+.25	−.86	−.11	+.21	−.30
West Virginia	−.99	−.45	−.87	−1.00	+.45	−.44
Maryland and Delaware	−1.02	−.35	−1.25	−.18	+1.73	−1.54
Virginia	−.12	−.20	−1.71	−.44	+.76	−2.03
North Carolina	+.45	+.22	−1.50	+.51	+.41	−2.08
Regional mean	−.76	−.20	−.84	−.02	+.20	−1.11

COTTON BOLL WEEVIL.

(*Anthonomus grandis* Boh.)[8]

The mild winter of 1920–21 and the wet summer of 1921 favored an abnormal multiplication of the boll weevil throughout the terri-

FIG. 23.—Increase in area infested by the cotton boll weevil in the United States from 1892 to 1921 in 10-year periods.

tory infested by this insect. The weevil has now reached the limit of cotton cultivation, except in western Texas, southwestern Oklahoma, northeastern North Carolina, and Virginia.

For the first time Missouri and Kentucky were invaded by the weevil, and all fields in these States were found to be infested.

The gain west of the Mississippi River is very nearly equal to that east of the Mississippi River. The greatest gain in a single State,

[8] Extracted from Department Circular 210, by B. R. Coad, E. S. Tucker, W .B. Williams, F. F. Bondy, and R. C. Gaines.

however, is 15,700 square miles in North Carolina. The gain in Texas was over 10,000 square miles which practically extends the line to that of 1915, the territory lost by the weevil since that year being thus regained.

In Oklahoma almost the entire cotton area is infested, while practically the same condition prevails in Arkansas.

In Tennessee several new counties were invaded in the western portion along the Mississippi River Valley.

The entire areas of cotton production in Georgia and South Carolina are totally infested. Altogether 66,662 square miles of new territory were invaded by the weevil in 1921, and there was no loss of territory at any point. This makes a total of 600,771 square miles infested in the United States, leaving only about 105,000 square miles of cotton territory still uninfested.

The accompanying map (Fig. 23) shows the increase in infested territory by 10-year periods since 1892. More detailed information on this subject may be obtained from Department Circular 210, United States Department of Agriculture.

PINK BOLLWORM.

(*Pectinophora gossypiella* Saund.)[9]

Prior to the discovery of this pest in Ellis County in the fall of 1921, there were five areas or districts of infestation known in Texas, namely, those of Hearne, Trinity Bay, Pecos Valley, Great Bend, and El Paso; a district in the southwestern part of Louisiana covering Calcasieu, Jeff Davis, and Cameron Parishes; a region continuous with the El Paso region in Dona Ana County, N. Mex., and a region closely related to the Pecos Valley district at Carlsbad in Eddy County, N. Mex.

Of the older areas of infestation the Hearne area has been apparently freed from the pest and is a demonstration of what can be accomplished where adequate control is maintained for a period of years. The Trinity Bay region has been reduced to a single locality at Moss Bluff in the southern part of Liberty County, and the infestations at Shreveport and in southwestern Louisiana have apparently been eliminated.

The entire success achieved by the establishment of noncotton zones in the three parishes of southwestern Louisiana, as shown by the elimination of cultivated cotton and the complete nonrecurrence of the pink bollworm in volunteer or other chance cotton in the district during the two years the noncotton zones have been maintained,

[9] Extracted from summary prepared under the direction of Dr. W. D. Hunter, Bureau of Entomology, Nov. 26, 1921.

has led to a substitution of a regulated zone for the noncotton zone in that district for 1922.

Only two new centers of infestation have been located—five fields in the vicinity of Ennis in Ellis County and a field near Marilee in Grayson County, in Texas. It is believed that these outbreaks originated from the seed of the crop of 1920 shipped from Carlsbad, N. Mex., prior to the determination of the incipient infestation at that point.

The Pecos Valley, Great Bend, and El Paso districts are almost certain to be reinfested every year under any system of clean-up or control which involves the continuation of the growth of cotton, or until such cooperation with Mexico is obtained as will lead to the

FIG. 24.—Geographical distribution of the pink bollworm in the United States in 1921 (solid-colored areas) and areas previously infested but reported free in 1921 (shaded areas).

cleaning up of the land on the Mexican side of the River and the freeing of the railway traffic from infestation at some interior point in Mexico.

On the accompanying map (Fig. 24) the shaded areas were formerly infested but were reported as free from the pink bollworm in 1921. The solid black areas were known to be infested in 1921.

JAPANESE BEETLE.

(*Popillia japonica* Newm.)[10]

The Japanese beetle, a native of Japan, was introduced into the United States in Burlington County, N. J., prior to 1916, presumably in the grub stage in soil about the roots of perennial plants. It was

[10] From reports of John J. Davis, C. W. Stockwell, and C. H. Hadley.

first discovered by H. B. Weiss and E. L. Dickerson, about the middle of August, 1916, in a nursery near Riverton. An interesting coincidence is that this insect was first discovered about a quarter of a mile from the place where the San Jose scale was first discovered in the eastern part of the United States.

The rate of increase has been remarkable. In 1916 about a dozen beetles were found, while in 1919, in the same locality, one person could collect by hand from 15,000 to 20,000 beetles in a day, and as many as 250 larvæ to the square yard.

FIG. 25.—Geographical distribution of the Japanese beetle in the United States since its discovery in 1916.

The area infested in New Jersey is mainly a market-garden and fruit-growing section, with Philadelphia as its chief market, while in Pennsylvania it is largely a residential section with much less land given up to farming. A considerable number of greenhouses and nurseries fall within this infested area, some handling only cut flowers, while others have a varied line of plants, bulbs, and outdoor-grown stock.

The area infested in 1916 covered approximately 0.9 square mile south of Riverton, N. J.; in 1917 this area had increased to 2.7 square miles; in 1918, to 6.8 square miles; in 1919 it had reached the Dela-

ware River to the north, and to the south had extended to Merchantville, in Camden County, and covered 48.3 square miles. In 1920 the pest was discovered across the Delaware River in Philadelphia and Bucks Counties, Pa., and had extended up the Delaware River on the New Jersey side as far as Burlington. In 1920 the area infested had reached 103.3 square miles; in 1921 the pest had spread to the south in New Jersey into Gloucester County, and to Medford and North Hampton in Burlington County. In Philadelphia County, Pa., it had extended to Frankford and Bustleton, and had touched the southern boundary of Montgomery County, while to the northeast it had extended to Bristol in Bucks County. It is now known to cover a territory of 270.1 square miles. (Fig. 25.)

The areas given for 1916, 1917, and 1918 are not necessarily exact since the earlier surveys were more or less general. The areas indicated for 1919, 1920, and 1921, however, are quite accurate, since very careful scouting was carried on during these years.

Beetles were discovered at two isolated localities to the southwest in Philadelphia County, one near the Delaware River, southwest of Elmwood, and the other on the west shore of the Schuylkill River in Fairmount Park.

SATIN MOTH.

(*Stilpnotia salicis* L.)[11]

The satin moth is common in Europe and is mentioned briefly in the writings of many European entomologists. It is reported as common in England and Ireland, its range extending from Spain to eastern Asia and as far north as Norway. One authority states that it occurs from Lapland to the middle of Italy and from England to Peking, China.

About July 1, 1920, a crew of men employed by the metropolitan park department found a number of Carolina poplar trees located on the Fellsway at the Malden and Medford City line, just north of Boston, Mass., that were being defoliated. S. S. Crossman, of the Bureau of Entomology, identified the insect as the satin moth, and this identification was later confirmed by the United States National Museum.

Scouting was immediately started and, as a result of this work, by the fall of 1920 the insect was known to occur over an area of 642 square miles including 60 towns in Massachusetts and 4 in New Hampshire. Inasmuch as large larvæ and pupæ were found in many of the towns, these towns were evidently infested the previous year (1919). During the year 1921 this insect was numerous in several towns and cities about Medford and Malden, where plantings of poplar suffered almost complete defoliation. Beyond this central

[11] By A. F. Burgess, Bureau of Entomology.

area the infestation can be considered as only slight. Very little territory was added this year to that infested in 1920. Rockland township is the first township in Plymouth County to be infested. Needham and Millis were added to the two towns already infested in Norfolk County. Holliston is added to the infested towns in Middlesex County, and Rye is added to the towns infested in Rockingham County, N. H.

Reports of this insect were received through the office of blister rust control, Bureau of Plant Industry, from Westminster, British Columbia, where the moth was reported as established in a park where it was thought to have been introduced on soldiers' equipment from the Gallipoli Peninsula, as the soldiers were quartered in this park on their return from the Dardanelles. It is reported that 80 per cent of the moths in Canada were killed during the winter by a parasite.

FIG. 26.—Geographical distribution of the satin moth in the United States: Solid-colored area, known to have been infested in 1920; uncolored named towns, infested in 1921.

Arthur Gibson, Dominion entomologist, says:

> During the past summer the outbreak of this insect in British Columbia extended to Vancouver Island. At the present time the insect is permanently established on the mainland adjacent to Vancouver and New Westminster and on Vancouver Island at Duncans.

This insect threatens poplars and possibly willows over the whole area of its distribution. So far, however, only the poplars planted for shade have suffered severely. The species has attacked Lombardy, Carolina, and Balm of Gilead, and undoubtedly will attack practically all of the species of poplar. The favored species usually occur singly or in small plantings over the area infested by this in-

sect at present. This may have a considerable influence in lessening the ravages of this species.

Two of the introduced enemies of the gipsy moth are vigorously attacking this host, namely, *Compsilura concinnata* Meig. and *Calosoma sycophanta* L. These two enemies are undoubtedly responsible for the checking of the damage done by the satin moth. Three native tachinid flies are also commonly bred from the larvæ of the species—*Tachina mella* Walk., *Euphorocera claripennis* Macq., and *Winthemia quadripustulata* Fab. *Telenomus californicus* Ashm. has been reared from the eggs.

The solid area on the map (Fig. 26) indicates the region infested in 1920, while the uncolored named towns are the additional ones infested during 1921.

Table 11 gives the departures from normal temperature and rainfall in New England in 1920–21.

TABLE 11.—*Monthly departures of temperature and rainfall in New England for the fall of 1920, the winter of 1920–21, and the growing season of 1921, used in connection with the 1921 summary of the gipsy moth, the brown-tail moth, and the satin moth.*

DEPARTURE (IN DEGREES FAHRENHEIT) FROM NORMAL TEMPERATURE.

	1920				1921								
	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.
New England	+1.7	+6.2	−1.4	+2.9	+3.4	+3.5	+9.4	+5.6	+0.8	+0.0	+3.0	−1.5	+3.3
DEPARTURE (IN INCHES) FROM NORMAL RAINFALL.													
New England	+2.00	−1.68	+1.09	+2.19	−1.48	−0.55	−0.64	+0.77	−0.76	−0.53	+1.10	−1.02	−1.12

GIPSY MOTH.

(*Porthetria dispar* L.)[12]

The gipsy moth, during 1921 and for a series of years preceding, has met with adverse conditions along its northern and northeastern borders of distribution. The weather conditions in the spring are usually favorable, when small larvæ are being carried by the wind, for its rapid dispersion in these directions, but the line of advancement is considerably impeded by the rapid change in the type of forest growth, the proportion of hardwoods to conifers changing rapidly. Large areas of practically clear coniferous growth are unfavorable to the development of larvæ, and such growth is found more or less in the regions mentioned above. Another serious obstacle in the more northern regions is the prevailing low tempera-

[12] By A. F. Burgess, Bureau of Entomology.

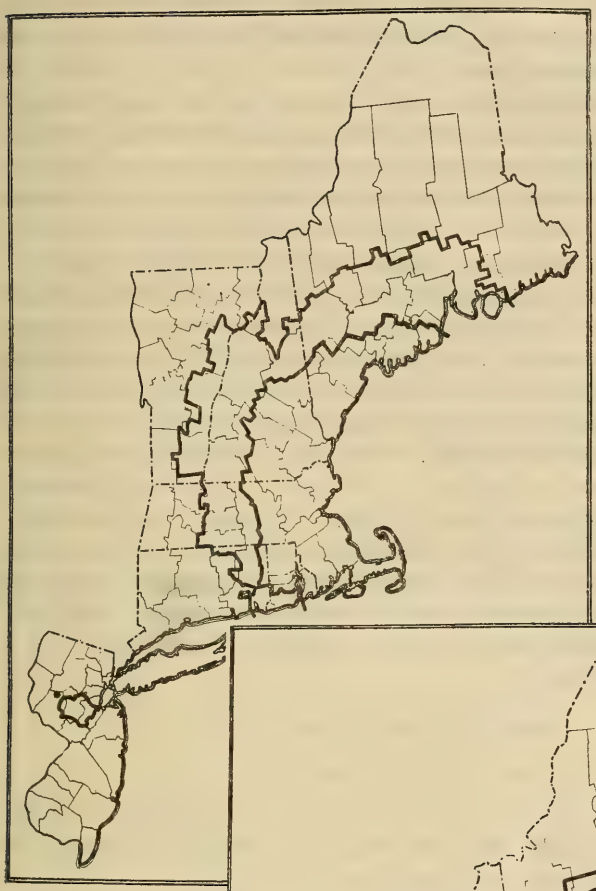

FIG. 27.—Geographical distribution of the gipsy moth in the United States: The inner line incloses the area of general infestation, while the area between the outer and inner lines and the area in New Jersey were only lightly infested in 1921.

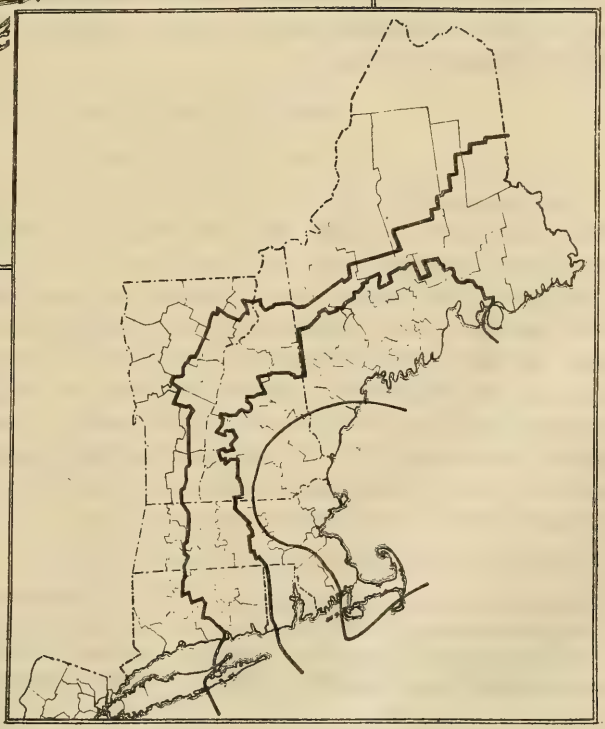

FIG. 28.—Geographical distribution of the brown-tail moth: The innermost line incloses the area of general infestation, the intermediate line limits the infestation of 1921, and the outermost line limits the infestation of 1914.

tures during the winter months. Extreme low temperatures are known to be fatal to the egg clusters that are deposited in exposed situations above the snow line.

The species is considered as a serious pest over the whole area of its distribution, although the actual damage to the foliage of trees in the area between the outer and inner lines on the map (Fig. 27) is but slight, and has been classified in the records of the gipsy moth laboratory as lightly infested, as is also the area in New Jersey. The area inclosed by the inner line on the map is classified as generally infested. It could not be said that the species was numerous enough in 1921 in all parts of this area actually to cause damage to the trees, but over the greater part of this area numerous defoliations occurred to forest, shade, and fruit trees, and over a considerable portion of this area complete defoliation involving extensive areas occurred.

During 1920 an infestation was discovered in northern New Jersey. This infestation now covers the greater part of Somerset County; Readington Township and east Amwell Township in Hunterdon County; and Middlesex County with the exception of the townships of Monroe, Madison, and Woodbridge. In Union County the insect has spread into the western corner covering Plainfield Township. An isolated infestation has also been located in Tewksberry Township in Hunterdon County.

BROWN-TAIL MOTH.

(*Euproctis chrysorrhoea* L.)[13]

The innermost line on the distribution map (Fig. 28) of the brown-tail moth indicates the area that was generally infested during 1921; although the pest could not be considered as serious throughout this entire area, it caused appreciable damage to fruit trees, and in several localities was so abundant that many apple and pear orchards were completely defoliated. The area between this line and the intermediate line on the map was slightly infested, the intermediate line bounding the area known to have been infested during the season 1921. It will be noted that this pest has materially receded from its maximum area of infestation attained in 1914, indicated on the map by the outermost line.

Arthur Gibson, Dominion Entomologist, says:

> This insect is being kept under control by the collection of the winter nests in the Provinces of Nova Scotia and New Brunswick, the only two provinces in Canada where this pest has gained a foothold. Practically no damage by the caterpillars has been effected under orchard conditions.

In the advance of this species to the north and northeast, conditions rapidly change with reference to its food plants. The pear, one of its

[13] By A. F. Burgess, Bureau of Entomology.

favorite food plants, is not commonly grown; the white oak, which was a favorite food plant during the period of the insect's greatest abundance in eastern Massachusetts and southern New Hampshire, is rarely met with in the northern sections of New Hampshire and Maine, inland from the sea coast; nor is the apple as common a tree in the latter sections as in the southern parts of New England. The lessened number of these favorite food plants, however, is not the only cause of the species failing to survive in the northern sections of New England. The adults sometimes move in tremendous flights, long distances from their origin, and after depositing their eggs their larvæ develop to the hibernaculum stage, where they are killed by the extremely low temperatures typical of these sections. Winter killing of the larvæ in their hibernacula is prevalent every winter in the sections mentioned above, and more or less so during severe winters in all sections of New England which are distant from the sea coast.

Introduced parasites and the native fungus *Entomophthora aulicae*, especially the former, are tremendous factors in the control of this species over the infested area.

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INTERNAL BROWNING OF THE YELLOW NEWTOWN APPLE.[1]

By W. S. Ballard, *Plant Pathologist, Office of Fruit-Disease Investigations*, and J. R. Magness and Lon A. Hawkins, *Plant Physiologists, Office of Horticultural and Pomological Investigations, Bureau of Plant Industry.*

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HISTORY OF THE INVESTIGATIONS.

It has been recognized for a number of years that certain apples grown under particular climatic conditions and held in cold storage at temperatures around 32° F. are liable to develop a peculiar browning of the tissue of the fruit. This trouble has no external symptoms and can not be detected from the outside of the fruit. It was first brought to the attention of investigators of the Bureau of Plant Industry during the storage season of 1905–6. In the fall of 1905 a series of storage experiments with apples from various sections of California was begun under the direction of G. Harold Powell. On examination of the fruit in the spring of 1906, apples from the Pajaro Valley were found to be affected by this premature browning of the flesh, which was designated as internal browning.

[1] This bulletin reports the results of cooperative work between the Offices of Fruit-Disease Investigations and Horticultural and Pomological Investigations of the Bureau of Plant Industry. C. W. Mann, E. M. Harvey, and H. R. Kraybill, formerly members of the staff of one or the other of these offices, and C. F. Kinman and H. C. Diehl, now with the Office of Horticultural and Pomological Investigations, have materially assisted in experimental work in this investigation.

This browning of the interior of the fruit had been up to this time frequently confused with frost injury, due to low temperature of the storage rooms, with the result that claims for damages had been made and allowed. In Powell's storage experiments the records showed that the temperature of the fruit had not been below freezing at any time. The storage work was continued in 1906 and 1907 with similar results. The Red Pearmain (probably Pomme de Fer), White Pearmain, Yellow Bellflower, Missouri, and Yellow Newtown varieties from the Pajaro Valley were all more or less affected with this tissue browning, while apples from other localities in California stored under precisely the same conditions were sound. In the hope of determining the cause of this trouble and working out some method of preventing it, an investigation was begun by Powell and his associates. In this work various experiments were conducted on the relation of character of the soil, of delayed storage, and of the state of maturity at which the fruit was picked to the prevalence of this browning in the stored fruit.

At the request of the Bureau of Plant Industry a soil survey of the Pajaro Valley was made by Mackie, of the Bureau of Soils, United States Department of Agriculture.[2] No definite results as to the cause of the disease or methods for its control were obtained by Powell. The accumulated evidence was mostly negative in character and as such, of course, of value in the continued investigation of the trouble. Inasmuch as Powell did not publish his results and the work of Mackie dealt entirely with the soil survey, there is no account of these earlier investigations in the literature. In 1912, however, Stubenrauch, who worked with Powell in the early part of the investigation and was later in charge of the work, reported on the effect of different storage temperatures on the occurrence of browning.[3]

In experiments started in 1909 covering two years Yellow Newtown apples from various portions of the Pajaro Valley were stored at different temperatures and inspected several times during the storage season. The method of inspection was to remove boxes of fruit from each lot, cutting half the apples in each box crosswise immediately upon withdrawal. The rest of the box was allowed to remain at common market temperatures for 10 days and was then cut and inspected. A large quantity of fruit, some 300 or 400 boxes, cut and inspected during these two years, furnished a means of determining rather accurately the extent of browning and its progress dur-

[2] Mackie, W. W. Soil survey of the Pajaro Valley, Calif. *In* U. S. Dept. Agr., Bur. Soils, Field Operations, 1908, 10th Rpt., pp. 1331–1372, fig. 37. 1911.

[3] Stubenrauch, A. V. Fruit handling, precooling, and storage investigations. *In* Ice and Refrigeration, v. 42, No. 1, pp. 34–36, 1912.

ing the season. Stubenrauch found that the browning develops as the season advances, being much worse in the later withdrawals. It was also found that apples stored at 35° F. were in much better condition than those at 32° as regards browning. On May 9, the last inspection, 64.2 per cent of bad internal browning occurred in the apples stored at 32° and only 13.2 per cent in the fruit held at 35° F. By bad browning is meant internal browning that would affect the commercial value of the fruit. The results of these experiments were furnished to the cold-storage trade of California, and the higher storage temperatures were adopted for Yellow Newtown apples from the Pajaro Valley.

Little further discussion of internal browning is found in any published report. Powell[4] mentioned the occurrence of this trouble in apples in discussing storage problems before the American Warehousemen's Association, and there is mention of it in the reports of the Chief of the Bureau of Plant Industry[5] for the years 1910, 1917, 1918, and 1920. It was recently mentioned and certain findings reported by the California Agricultural Experiment Station.[6]

Many data on the earlier work on this trouble were obtained from the files of Field Investigations in Pomology, and some were furnished by William A. Taylor, formerly in charge of that office, and L. C. Corbett, now in charge of the Office of Horticultural and Pomological Investigations. C. W. Mann, who was associated with Stubenrauch in the later work on this problem, also furnished some information. As none of the present writers were connected with this work prior to 1917, it is probable that due credit may not be given the various men who have worked on this problem. In addition to those already mentioned, L. S. Tenny, H. J. Eustace, H. M. White, G. W. Hosford, H. J. Ramsey, A. W. McKay, and probably others have been connected with this work at some time, and the status of the problem when it was taken up by the present writers was due to their combined efforts.

The foregoing short historical sketch serves to introduce the present bulletin, in which an attempt is made to bring the account of this work up to date and to give some results of the further study for three years of this peculiar storage trouble of apples.

The Pajaro Valley apple district centers around Watsonville, about 100 miles south from San Francisco and near the coast. It is the most extensive apple-growing section of California, comprising

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[4] Powell, G. Harold. [Internal browning of apples.] *In* Ice and Refrigeration, v. 36, No. 1, pp. 8–9. 1909.

[5] U. S. Department of Agriculture, Bureau of Plant Industry. Report of the Chief of the Bureau of Plant Industry, 1909–10, 1916–17, 1917–18, 1919–20. Washington, D. C., 1910–1920.

[6] Webber, Herbert J. Internal browning of the Newtown from the Pajaro Valley. *In* Calif. Agr. Exp. Sta. Rpt., 1919–20, p. 42. 1920.

in 1918 about 19,000 acres of orchards, practically all in bearing. The production for that year was approximately 4,500,000 packed boxes, or more than two-thirds of the apple crop of the State. The Yellow Newtown comprises more than half of the production of the district, while the Red Pearmain, another very susceptible variety, constitutes probably about one-thirtieth of the total output. A large part of the Yellow Newtown crop is marketed within the State, a portion is shipped to the central and eastern United States, and considerable quantities are exported. The bulk of the crop is packed in boxes and placed in cold storage, inasmuch as the Yellow Newtown is a long-keeping variety, capable of retaining its quality until late winter or early spring. It is evident from this description that, considering the total apple production of the United States, the percentage of the crop in danger of serious depreciation on account of internal browning is not large. Great financial losses, however, have resulted in the past to the apple growers of the Pajaro Valley from this deterioration of the stored fruit. It is therefore vitally important to the prosperity of this district that this trouble be investigated and methods worked out for its control.

So little has been written about this particular storage trouble that it has acquired no well-established name in commercial circles. It is sometimes referred to by the trade as "dry-rot," but that name is inappropriate, for the reason that the diseased tissue shows no noticeable drying out. The term "internal browning" was chosen because it suggests the appearance of the diseased tissue and also its location in the flesh of the apple. Since this internal browning develops only in low-temperature storage, the term "storage internal browning" would be more descriptive but is probably too long to come into general use.

DESCRIPTION OF INTERNAL BROWNING.

Careful investigations have established the fact that internal browning is not caused by a fungous or bacterial parasite. It is the result of certain abnormal physiological activities in the flesh of the apple classed in the general group of so-called physiological diseases. Internal browning does not appear in the fruit on the trees and does not develop if the apples are held at room temperature after picking. Regardless of some opinions to the contrary, it is not possible to predict from the external appearance of an apple whether or not internal browning will be found when the apple is cut open. In other words, internal browning does not manifest itself by any abnormal appearance of the skin of the fruit. It will be noted that this character is in contrast to the conditions obtaining in some other

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A Hoens Co Baltimore

INTERNAL BROWNING OF YELLOW NEWTOWN APPLES.—I.

FIG. 1.—Cross section showing core lines. This condition of fruit is termed "sound."
FIG. 2.—Cross section showing bad internal browning within the core lines and only traces outside this region. This condition represents "trace tissue" and "bad core."

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A Hoen & Co Baltimore.

INTERNAL BROWNING OF YELLOW NEWTOWN APPLES.—II.

FIG. 1.—Cross section showing extent and distribution of internal browning classed as "medium tissue" and "medium core." FIG. 2.—Cross section showing "bad tissue" and "trace core" browning.

physiological diseases, such as Jonathan spot, bitter-pit, and scald, in which discolored spots may appear in the skin of the fruit.

Plates I and II show various degrees of internal browning as it appears in cross sections of Yellow Newtown apples. It will be seen that internal browning may appear anywhere in the flesh of the apple, either immediately around the core or farther out toward the skin. Quite frequently internal browning appears only around the core, the outer fleshy portion of the apple remaining normal in appearance. On the other hand, though less frequently, only the outer flesh is involved. Usually when internal browning develops in the outer fleshy portion it is accompanied by browning around the core. There seems to be a tendency, however, for it to occur symmetrically as regards the morphology of the fruit. In very mild cases when an apple is cut crosswise only a small spot faintly tinged with brown may be seen in the angle between two adjacent seed cavities, the remainder of the cut surface appearing quite normal in color. In other cases faintly browned areas may appear around the core, accompanied by one or more discolored areas of various sizes and degrees of browning in the fleshy portion of the apple. Thus, all gradations from normal to badly browned core areas may be accompanied by equally varied conditions in the outer flesh of the fruit.

Frequently, in mild cases, a section through the widest diameter may show no internal browning, while further cutting, particularly toward the stem end, may reveal traces of this discoloration.

The fruit at picking time shows no visible indication of internal browning, and it is evident that the tendency to develop this trouble in storage is inherent in the fruit when it comes from the tree. Just what factors or conditions of the fruit determine this tendency the writers are not prepared to say, though interesting suggestions on this subject will be brought out later.

In presenting the results of these investigations it has seemed undesirable and unnecessary to include the long tables of figures and data that have accumulated from the work of each year. The data bearing on the most important phases of the subject have been condensed and tabulated for the purpose of giving the reader a clearer understanding of the results. Considerable information has been accumulated on certain chemical and physiological phases of apple storage as a result of investigations conducted for the purpose of learning something about the inherent differences between normal apples and apples subject to or showing internal browning. Unfortunately much of that work has contributed relatively little toward an understanding of the problem in hand, but the information gained is of value as an addition to our relatively meager knowledge of the physiology of cold-storage fruits.

EXPERIMENTAL WORK.

Previous to the time the present writers took up the work on internal browning considerable attention had been given to obtaining individual tree records from a number of orchards in the Pajaro Valley. This work has been continued and modified in some respects. Most of the work has been confined to orchards on the floor of the valley, but sufficient data have been obtained from trees growing at higher elevations, in the so-called mountain orchards, to establish a definite contrast in the susceptibility to internal browning of the two types of fruit. In addition fruit from a number of individual Yellow Newtown trees in the Yakima and Wenatchee Valleys of Washington and in Albemarle County in Virginia have been shipped to Watsonville and held in storage for comparison with the locally grown fruit. In this experimental work some attention has been given to the Red Pearmain variety, but for the most part the investigations have been confined to the Yellow Newtown, because of its greater commercial importance. Trees under observation have been marked by numbered indestructible metal tags. At picking time the desired quantity of fruit from each tree has been packed in commercial apple boxes and the boxes marked with the tree and orchard number. After picking, the fruit practically always has been placed in cold storage within 24 to 36 hours.

The fruit from the various orchards was picked each year at the time when the commercial harvesting was in progress in the particular orchards, and an attempt was made to gather apples from all parts of the tree, so that each box represented as nearly as possible a uniform sample of the crop on the tree. Usually, when only a record of internal browning was wanted, a single box was all that was taken from a tree. If it was desired to compare the effect of various storage temperatures on fruit from a certain tree or if larger quantities were wanted for experimental work, the required quantity was picked and carefully mixed before packing, in order to insure as far as possible a uniformity of fruit throughout the entire number of boxes.

During the progress of the investigations with which the present writers have been concerned, more or less continuous records have been obtained from a total of about 150 trees. During that time about 800 boxes of fruit have been carefully examined, and for the most part a record of the internal browning in each individual apple has been made.

The fruit has usually been left in storage until May or June, to allow the maximum development of internal browning. At the time of inspection the apples were examined as soon after removal from storage as possible, and in no case was the fruit taken from storage

allowed to stand more than a few hours before being inspected. With the exception of the crop of 1920, only half of each box was inspected immediately on removal from storage. The remaining half was then held for 10 days at room temperature and at the expiration of that time was inspected for the purpose of determining the increase in internal browning during that interval. This 10-day period after withdrawal from storage was chosen to represent the interval that might elapse in commercial marketing between the time of removal from storage and the consumption of the fruit by the ultimate purchaser. In the spring of 1921 the inspection at 10 days after removal from storage was omitted, the entire box being examined on withdrawal.

The method of recording internal browning requires some explanation. Mention has been made of the fact that internal browning often occurs only around the core and again, though much less frequently, only in the outer flesh of the apple. Thus, one may distinguish two types of the disease, and very often both types occur in the same apple. It has seemed desirable, therefore, to record the region in which internal browning has appeared in each apple examined, and also an approximation of the extent or intensity of the discoloration.

On examining cross sections of a Yellow Newtown apple (Pl. I, Fig. 1), a fine greenish line will be noted, which incloses an irregular, somewhat star-shaped area surrounding the seed cavities. For convenience in recording internal browning data, this area surrounding the seed cavities and bounded by this so-called core line has been termed the core region, and internal browning occurring in this region has been designated "core browning." Internal browning appearing outside the core line has been termed "tissue browning." The designations "core browning" and "tissue browning" are both open to criticism, but when their significance, as just explained, is kept in mind they will serve to characterize briefly the two types of internal browning which may occur. Obviously, also, the extent of tissue browning or of core browning varies in different apples, and it has been necessary to adopt some method of classifying each apple as to the extent of tissue or core browning it shows. Three grades—trace, medium, and bad—have been arbitrarily established, and so far as possible each grade has a commercial significance. The term "trace" indicates such a small extent of internal browning as would probably cause no depreciation in the commercial value of the fruit and includes those stages from the faintest discoloration, discernible only after considerable experience, to a more evident but still comparatively slight tinge of brown color. The term "medium" signifies a distinct browning, sufficient to detract somewhat from the commercial value of the fruit, while "bad" characterizes those stages

more pronounced than "medium" and sufficiently marked to lower the value of the fruit appreciably or even make it unsalable. The descriptions on page 5 accompanying Plates I and II will assist the reader in understanding the significance of the terms "trace," "medium," and "bad" as used in classifying the intensity of internal browning. It will be seen that these three classes grade from one to another with no sharp distinctions between successive classes, so that they serve only as a rough method of estimation.

The method of inspecting the fruit and recording the internal browning was as follows: Each apple was cut crosswise into approximately equal parts and the presence or absence of browning was noted. If no browning appeared the apple was recorded as sound regardless of any other imperfections that might be present. If internal browning was present, a record of its location, whether "core" or "tissue," and the extent, "trace," "medium," or "bad," was made. The total number of apples cut from each box was recorded and the records for each box and each tree were kept separately.

For the most part the fruit has been held in commercial cold-storage houses. In one of these houses the air circulation system was employed, air being cooled in a bunker room and circulated by fans through the storage rooms and back to the bunker room again. In the other plant each room was cooled by means of brine coils supported near the ceiling. In this case there was, of course, very little air movement within the storage rooms and no effort at ventilation. The concentration of carbon dioxid was sufficient at times to make it impossible to light a match. No direct comparison was made of the keeping quality of fruit stored in these two types of storage houses, but from general observations there appeared to be no noticeable difference.

RELATION OF INTERNAL BROWNING TO STORAGE CONDITIONS.

Previous to the year 1910 apples from the Pajaro Valley district were stored at temperatures around 32° F., approximating cold-storage temperatures used for apples throughout the United States. At that time, however, certain observations by Stubenrauch and other workers of the Bureau of Plant Industry led to the belief that internal browning developed to a much greater extent at temperatures near 32° than at 35° to 40° F. Consequently, after the year 1910 the commercial cold storages at Watsonville and other points in California, where the tendency of this fruit to develop internal browning in storage was known, raised the temperatures of their apple-storage rooms to 35° F. With the 1917–18 storage season, the temperature of storage was raised to 36° F. This is the temperature

still held in most of the apple storage houses of California, though some have recently been holding the rooms at 38° F.

Since the inauguration of temperatures of 36° F. or above in the holding of apples from this district little internal browning of commercial importance has occurred. This, in the light of the definite experimental data obtained during three seasons, has undoubtedly been due to the fact that the fruit has been held at higher temperatures during recent years.

In the autumn of 1918 one box of fruit was picked from each of 24 trees and shipped by express to Washington, D. C. There the fruit was at once placed in storage at 32° F. Exactly similar boxes from the same trees were held at Watsonville at 36° F. Although a possible error, due to different storage houses, time in transit, etc., is introduced, the fact that the lots of fruit were closely comparable when picked makes the data of much interest in connection with the temperature of storage which causes greatest development of internal browning. These data are presented in Table 1.

TABLE 1.—*Extent of the internal browning of Yellow Newtown apples stored at different temperatures in the season of 1918–19.*

[Fruit samples stored at 36° F. were so held at Watsonville, Calif., where grown; those stored at 32° F. were first shipped to Washington, D. C.

Temperature and time of sampling.	Number of trees.	Fruit sampled.		Comparison of results (per cent.)						
		Half boxes.	Number of apples cut.	Sound.	Tissue browning.			Core browning.		
					Trace.	Medium.	Bad.	Trace.	Medium.	Bad.
Held at 36° F.:										
At withdrawal..	24	24	1,429	32.0	9.2	5.1	5.2	15.5	18.3	27.9
Ten days later..	24	23	806	21.8	11.3	5.6	2.6	10.8	17.4	63.3
Held at 32° F.:										
At withdrawal..	24	24	1,161	28.6	10.1	10.9	20.1	25.1	18.2	20.2
Ten days later..	23	23	1,012	12.6	4.4	6.6	39.5	8.4	18.7	56.5

The summaries presented, representing samples of fruit from 24 different trees, indicate clearly that the apples shipped to Washington and there held at 32° developed much more internal browning than did those stored immediately at 36° F. at Watsonville. This is particularly true of the bad tissue browning, which, of course, is most serious from the commercial point of view. It was planned in further experiments to determine more accurately the effect of storing at different temperatures fruit treated in the same way and held under conditions exactly similar except for temperature.

During the autumn of 1919, 3 boxes of fruit were picked from each of 10 trees, care being used to obtain 3 boxes as nearly uniform as possible. These were forwarded by express to the University of California at Berkeley and stored in the experimental cold-storage plant of the pomology department. One box from each tree was stored at 32° F., another at 36°, and the third at 40°. Owing to an

accidental lowering of temperature, the apples in the room scheduled for 32° F. were badly frozen, so that no internal browning records could be obtained from this fruit. Although only a small amount of browning showed in either of the lots held at the higher temperatures, the summary, as given in Table 2, shows much more browning in the fruit held at 36° than in that stored at 40° F.

TABLE 2.—*Extent of the internal browning of Yellow Newtown apples stored at Berkeley, Calif., at different temperatures in the season of 1919–20.*

Temperature.	Number of apples cut.	Comparison of results (per cent).						
		Sound.	Tissue browning.			Core browning.		
			Trace.	Medium.	Bad.	Trace.	Medium.	Bad.
Held at 40° F	756	87.3	1.6	0.13	0.13	5.4	3.4	2.1
Held at 36° F	812	64.7	11.2	1.2	.1	13.4	8.9	7.0

TABLE 3.—*Extent of the internal browning of Yellow Newtown apples stored at different temperatures in the season of 1920–21.*

Tree and temperature.	Number of apples cut.	Comparison of results (per cent).						
		Sound.	Tissue browning.			Core browning.		
			Trace.	Medium.	Bad.	Trace.	Medium.	Bad.
Tree 1 (sprayed):								
At 31° F	55	0	12.7	40.0	45.5	10.9	36.3	50.9
At 38° F	62	46.8	0	0	0	40.3	8.1	4.8
Tree 10:								
At 31° F	34	0	14.7	20.6	61.7	14.7	17.6	67.6
At 38° F	43	23.3	0	0	0	39.5	23.3	14.0
Tree 69:								
At 31° F	47	21	44.7	13.4	17.0	29.8	44.7	21.3
At 38° F	51	43.2	9.8	0	0	45.1	3.9	7.8
Tree 134:								
At 31° F	178	30.9	21.9	10.7	8.4	45.5	14.0	7.3
At 38° F	82	85.5	0	0	0	7.3	4.9	2.4
Tree 142:								
At 31° F	90	0	8.9	18.9	71.1	10.0	27.8	62.2
At 38° F	66	40.9	44.0	0	0	45.5	4.5	0
Tree 143:								
At 31° F	56	3.6	21.4	8.9	53.6	17.9	23.2	53.6
At 38° F	63	33.3	22.2	4.8	0	50.8	11.1	1.6
Tree 260:								
At 31° F	86	0	12.8	27.9	55.8	7.0	17.5	76.8
At 38° F	63	1.6	46.1	17.5	3.2	15.9	34.9	47.6
Tree 262:								
At 31° F	67	0	4.5	22.4	73.2	1.5	9.0	23.9
At 38° F	77	18.2	13.0	0	0	44.2	11.7	13.0
Tree 280:								
At 31° F	123	17.9	35.8	8.9	0.8	52.8	20.3	7.3
At 38° F	95	91.7	1.1	0	0	4.2	3.2	1.1
Tree J 247:								
At 31° F	48	62.5	14.6	0	0	37.5	0	0
At 38° F	68	95.6	0	0	0	2.9	1.5	0
Tree J 248:								
At 31° F	64	28.1	37.5	1.6	0	62.5	9.4	0
At 38° F	78	93.7	0	0	0	5.1	0	1.3
Tree 33:								
At 31° F	52	1.9	30.8	30.8	21.2	23.1	34.6	38.5
At 38° F	68	36.8	2.9	0	0	32.4	13.2	17.7
Summary:								
At 31° F	900	14.3	21.9	16.4	30.2	29.7	20.0	30.1
At 38° F	816	54.4	11.0	1.7	0.25	25.6	9.2	8.6

During the fall of 1920 duplicate boxes of fruit were picked from each of 12 trees. One box from each tree was stored at 38° F. and the other at a temperature that fluctuated somewhat but averaged about 31°. At the time the fruit was stored the temperature was somewhat below 31°, but was raised until by the time the inspection was made in March it was about 33° F. The average represents about the temperature at which apples are usually held in cold storage at points outside of California. Table 3 gives in detail for each tree the percentage of browning of fruit in the 38° storage and that at 31° F.

From an examination of the data presented in Table 3 it is at once apparent that whereas very bad internal browning had developed in fruit held at 31° there was very little in that held at 38° F. As was noted in describing the browning, fruit listed as "trace," whether tissue or core, shows so little discoloration that it is practically negligible from the commercial viewpoint. Medium and bad core browning represent discoloration about the core that detracts from the value of the fruit. The medium and bad tissue browning represent marked discoloration throughout the flesh of the fruit outside the core line and may render the fruit practically unsalable. Of the fruit held at 31° F. more than 46 per cent was in these last two classes, while less than 2 per cent of that held at 38° showed this degree of browning. It is obvious from the data presented that if the commercial fruit from the Pajaro Valley stored during the season of 1920–21 had been kept at the 30° to 32° F. temperatures used for apples in most sections of the country the loss would have been very severe. Fortunately, most of it was held at 36° to 38° F., so that the discoloration was not sufficient to affect seriously the marketability of the fruit.

Of special interest to the commercial industry is the question of the development of the internal browning upon the removal of the fruit from cold storage. A certain period must necessarily elapse between the time of removal of the fruit from cold storage and its ultimate consumption. In practically all these investigations an inspection was made at the time the fruit was withdrawn from storage and another after the fruit had remained out of storage for 10 days. As has been mentioned, half of each box was cut at the first inspection and the remaining half at the second, so the results are very closely comparable. A summary of the data is presented in Table 4.

TABLE 4.—*Progress of the development of internal browning in Yellow Newtown apples after removal from cold storage in three different seasons.*

Storage season and orchard.	Time of inspection.	Apples cut.	Bad tissue browning.	Bad core browning.	Temperature of storage.
		Halfboxes.	*Per cent.*	*Per cent.*	*°F.*
Season of 1915–16:					
Rodgers Bros. orchard	At withdrawal	51	10.5	13.1	35
	10 days later	51	15.5	19.9	
Floyd Rodgers orchard	At withdrawal	68	10.5	12.8	35
	10 days later	68	22.9	29.7	
Season of 1916–17:					
Rodgers Bros. orchard	At withdrawal	61	19.3	23.7	35
	10 days later	61	29.0	40.4	
Floyd Rodgers orchard	At withdrawal	52	29.8	30.2	35
	10 days later	52	34.7	41.7	
Season of 1918–19:					
Rodgers Bros. orchard	At withdrawal	311	2.6	6.1	36
	10 days later	311	2.4	17.9	
Floyd Rodgers orchard	At withdrawal	150	3.1	22.3	36
	10 days later	150	3.6	46.5	
Rodgers Bros. orchard	At withdrawal	19	14.3	11.0	32
	10 days later	19	16.6	17.7	

It is apparent from the data in Table 4 that there is a marked increase in the extent of internal browning in the 10 days under market conditions after the fruit has been removed from cold storage. Large quantities of fruit were used in the storage experiments, so that the averages presented correspond closely to what may be expected under commercial conditions. Only the data for bad tissue and bad core browning have been presented, as these conditions are most important in affecting the sale of the fruit.

During the seasons of 1915–16 and 1916–17 considerable browning developed, and the increase after removal from storage was very marked. In 1917–18 so little browning developed that the data are not included. In 1918–19 the tissue browning was very light and the increase following removal from storage was less marked, although core browning was much more in evidence at the second inspection. From the data presented it is obvious that if browning is present in the fruit while in cold storage it may be expected that this will be much worse by the time the fruit reaches the consumer.

RELATION OF INTERNAL BROWNING TO ORCHARD CONDITIONS.

Certain peculiar characteristics of the occurrence of internal browning early directed the attention of investigators to the importance of a study of orchard conditions in relation to this trouble. The fact that the browning occurs much more commonly in apples from the Pajaro Valley than in fruit grown in other parts of the United States has directed attention to a study of various factors of orchard management in that district in relation to their effect on browning. These studies include observations on the compara-

tive tendency to internal browning of apples from various parts of the district, the effect of thoroughness of orchard tillage and of various commercial fertilizers and barnyard manure on this tendency, a study of individual trees to determine whether the production of apples which brown in storage is a tree characteristic, and finally a detailed study of tree characteristics, such as quantity and condition of foliage, size of crop, and the size of individual apples on the trees. These have been augmented by chemical and physiological studies of fruits remaining sound as compared to those becoming browned in storage.

The Pajaro Valley is almost surrounded by mountains or hills which are very low toward the sea, some 4 to 8 miles distant from the apple plantings, and rise to considerable heights on all other sides of the valley. Most of the orchards are on the floor of the main valley, though a number extend up some distance on the surrounding hills and into smaller valleys which are cut off from the ocean by ranges of hills much higher than those bordering the Pajaro Valley proper.

As in California generally, the year is divided into two seasons, the rainy and the dry. The rainy season extends from October to April, inclusive, and during that time there is an average precipitation of about 25 inches. Throughout the remainder of the year showers are rare and of practically no importance. The winter weather is mild, and comparatively little frost occurs.

In the summer and early fall the valley is subject to low-velocity trade winds from the ocean. They begin to blow between 10 o'clock and noon and continue until late afternoon. As a result, the evenings are cool or even chilly. Frequently the winds bring in fogs, which begin to cover the valley about 4 o'clock in the afternoon and remain until 9 or 10 o'clock the following morning. These fogs are of two types, high and low. The high fogs are at an elevation of several hundred feet, while the low fogs lie close to the ground, enveloping the trees, and sometimes drenching the foliage during the night and early morning. The points to be noted in this connection are the cutting off of the direct sunshine and the consequent lowered temperature and increased humidity during the growing period. This foggy weather is interspersed with clear periods of 2 to 10 days. The daily fluctuation of temperatures is between 50° and 65° F. during the foggy weather and between 65° and 80° F. during the clear period. Temperatures above 90° F. are rare, occurring not oftener than once or twice during the summer and early fall. These fogs are relatively much more prevalent over the floor of the valley proper, which is open to the sea, than over the higher foothill regions or over the more protected interior-valley orchards. These

foothill and inland orchards have relatively a somewhat higher temperature, more sunshine, and lower humidity.

For several years fruit has been gathered from orchards located well up on the hills, above the fog belt, and also from several different orchards down on the floor of the valley. The fruit from these different orchards has been handled in the same way, stored under similar conditions, and inspected in the spring to determine the distribution of orchards producing fruit which tends to brown internally during storage. This fruit has been compared with Yellow Newtown apples from Virginia and from the Yakima and Wenatchee districts of Washington.

Some internal browning has been found to occur in Yellow Newtown apples from all these fruit-growing sections as well as from all parts of the Pajaro Valley apple district. From the sections outside the Pajaro district, however, and in the hill orchards in that district, internal browning has been found only to such a small extent as to be of little importance in a commercial way. Only in fruit from the orchards on the floor of the valley, in the summer fog belt and growing in soil of very high fertility, has this trouble been particularly serious. These observations are based on the inspection of hundreds of boxes of fruit extending over several years. The detailed records of these inspections are much too voluminous to be included in this bulletin.

RELATION OF INTERNAL BROWNING TO SOIL FERTILITY AND FERTILIZERS.

In order to determine whether internal browning is related to any soil deficiency either of an organic or of an inorganic constituent, a series of fertilizer plats was laid out in 1917 and initial applications were made. Three plats were established, trees outside the plats receiving no fertilizer treatment serving as a check. Each plat contained 15 trees.

Plat 1, known as the nitrogen plat, received 10 pounds of ammonium sulphate per tree in 1917. As the trees were very large and no appreciable response could be detected from this treatment, the quantity was increased to 20 pounds in 1918. In 1919 sodium nitrate was used instead of the ammonium sulphate, and in 1920 20 pounds of ammonium sulphate were again added.

Plat 2, the manure plat, was started in the spring of 1917. Soil was removed from around the trees in an area equal to about the spread of the branches, and about a ton of barnyard manure was applied at the base of each tree. In addition, 20 pounds of steamed bone meal, containing about 20 per cent of phosphoric acid and 4 per cent of nitrogen, were added for each tree. Thus, each tree in the plat was very heavily fertilized with phosphoric acid, nitrogen, and organic matter, while considerable potash was available in the manure. No subsequent applications of fertilizer were made.

Plat 3, the phosphorus plat, received 20 pounds of superphosphate per tree on April 3, 1918. In 1919 10 pounds of superphosphate and 10 pounds of steamed bone meal were added. In 1920 6 pounds of steamed bone meal were added for each tree.

All fertilizers were applied in the spring before cultivation was completed, and were thoroughly worked into the soil.

GROSS EFFECT OF FERTILIZERS.

During the first two seasons little influence of the fertilizer could be detected in any of the plats. During 1919, however, it was evident that the foliage of the trees of the nitrogen plat was better than that of the surrounding trees, the leaves being larger and greener in appearance. In 1920, a year of very short crops for the orchard as a whole, trees in this plat produced more nearly a full crop.

It has been impossible to determine any influence of the phosphorus fertilizer in plat 3. Foliage, crop, and fruit were about as in the untreated trees in the orchard.

Trees in the manure plat were no better in appearance than surrounding untreated trees. The foliage was very poor, and the set of fruit on the trees in the years when the orchard as a whole bore a light crop was even below that of the surrounding trees.

INFLUENCE OF FERTILIZERS ON THE INTERNAL BROWNING OF THE FRUIT.

Table 5 gives the average percentages of browning in fruit from each fertilizer plat during the seasons of 1918–19 and 1920–21, during which browning has occurred to an appreciable extent, since the treatment was initiated.

TABLE 5.—*Summary of the influence of fertilizers upon the internal browning of Yellow Newtown apples in two different seasons.*

Season, plat, and treatment.	Number of trees.	Number of apples cut.	Comparison of results (per cent).						
			Sound.	Tissue browning.			Core browning.		
				Trace.	Medium.	Bad.	Trace.	Medium.	Bad.
Season of 1918–19; storage temperature, 36° F.:									
Plat 1, nitrogen	15	982	48.7	10.2	10.2	10.7	17.6	13.2	9.2
Plat 2, manure	15	1,004	11.4	24.4	16.6	8.3	16.9	29.9	33.5
Plat 3, phosphorus	15	945	27.4	8.0	3.1	1.9	19.2	22.5	24.7
Plat 4, check	9	817	23.9	15.2	8.3	5.9	16.5	25.1	26.3
Season of 1920–21; storage temperature, 31° to 32° F.:									
Plat 1, nitrogen	15	1,560	18.4	24.4	16.3	17.8	38.2	21.0	18.6
Plat 2, manure	15	1,571	8.7	25.1	14.1	25.1	29.4	27.0	30.9
Plat 3, phosphorus	15	1,543	9.0	28.0	22.9	13.9	33.4	37.5	20.2
Plat 4, check	9	967	7.1	31.9	13.5	10.4	32.0	34.1	26.0

A study of the data presented in Table 5 shows that there was no clear-cut response to the fertilizer treatment as evidenced in the fruit. Certain observations on the effect of these fertilizers are worthy of note. Each year there was a markedly higher percentage of sound fruit in the nitrogen plat than in any other. The percentage of bad tissue browning in the fruit from trees of this plat, however, was also highest during the first season and second only to that of the manure plat the second year. In checking over the individual tree records on this plat, the remarkable fact has developed that during each year the trees producing the highest percentage of fruit which became badly browned were in this nitrogen plat. The foliage and general appearance of these trees have been the best of those under test, and generally the fruit has been either exceptionally good or exceptionally bad in its tendency to brown internally. These phenomena will be considered further under the subject of crop yield and browning.

The phosphate and check plats have had only a moderate percentage of browning. There has been little sound fruit, however. Generally, the fruit has shown traces of browning, with little entirely sound and little particularly bad.

On the whole, there has been a higher average percentage of browning in the manure plat than in any other. The percentage of sound fruit has been low, and there has been an abundance of bad browning, particularly bad core browning, in the fruit.

In general, it may be said that the results have been negative so far as causing or preventing browning through fertilizers is concerned. The points brought out are of interest, however, particularly when viewed in the light of the relationship of browning to yield, discussed later in this bulletin.

RELATION OF INTERNAL BROWNING TO THE INDIVIDUAL TREE.

During the early investigations of this trouble it was apparent that there is oftentimes a very distinct variation in the extent of browning which appears during storage in fruit from different trees, even when such trees are growing adjacent to each other. Consequently, for the past six years fruit from the different trees in the orchards under observation has been kept separate, and the average performance records of a large number of trees over a period of several years have been obtained. Only the summaries of these records will be presented here.

It was in the minds of the investigators during the first years in which these records were made that the tendency of the fruit to brown in storage is a tree characteristic and that certain trees tended to produce fruit year after year that was inherently sound, while other trees regularly produced fruit that tended to become

badly browned after a season in cold storage. After the records of the work of three seasons were available, however, it was evident that this condition does not hold true. In certain instances, trees have produced sound fruit a number of years in succession, while others have produced fruit with a tendency to bad browning in successive years. But this condition by no means holds generally, and very often a tree which produces sound fruit one year will produce fruit tending to brown very badly the next year. In other words, it is impossible to predict what a tree will do, basing the prediction on its previous performance record.

DEFOLIATION AND GIRDLING EXPERIMENTS.

In order to obtain evidence, if possible, upon the internal condition of nutrition in the trees that are associated with the occurrence of browning, it was planned during the summer of 1919 to vary the nutritive conditions in different parts of the same tree and to determine the effect of these treatments on the development of internal browning.

Six trees were selected for special treatment, three of which during the preceding year had produced fruit that tended to brown badly and three of which had produced fruit that remained sound. All trees were bearing heavy crops of fruit.

Branches as nearly uniform as possible and ranging from 1 to 2½ inches in diameter were selected. On each tree certain branches were girdled by removing a ring of bark one-eighth to one-fourth inch wide around the branch near its base. Other adjacent and similar branches were treated by removing about half the leaf area from the branches. Partially defoliated branches in all cases were well loaded with fruit, while in the cases of girdled branches the number of apples on each branch was reduced by thinning until no two fruits were closer together than 5 inches. All of this work was done on June 26, 1919, when the fruit was about three-fourths of an inch to 1 inch in diameter. Adjacent branches receiving no treatment served as checks to the treated ones.

Fruit on the girdled branches was very large at the time of picking, which was in the first week of October. It was yellow tinged and well ripened and had a tendency to water core. The fruit on branches that were partially defoliated, on the other hand, was small and green in appearance at the time of picking. Normal fruit on the same trees was intermediate in degree of apparent maturity and in size. Chemical analyses made at the time of picking and again at the time of the inspection of the fruit upon its removal from storage in May, 1920, showed that the fruit from girdled limbs was markedly higher in both total sugar and in

titrable acid than normal fruit from the same trees, while fruit from the defoliated branches was lower in both sugar and acid. The very marked differences in size and appearance of the fruit from girdled and from defoliated branches, as well as the distinctive variation in sugar and acid in fruit following these two methods of treatment, together with the records on internal browning of the fruit, make this experiment of considerable interest. The data are given in Table 6.

TABLE 6.—*Effect of girdling and of defoliating branches upon the development of internal browning and upon the acid and sugar content of fruit during the growing season of 1919.*

Tree and treatment of branches.	Number of apples cut.	Comparison of results (per cent).									
		Sound.	Tissue browning.			Core browning.			Titratible acid (as malic).		Total sugar, June, 1920.
			Trace.	Medium.	Bad.	Trace.	Medium.	Bad.	Oct., 1919.	June, 1920.	
Tree 3 (sprayed):											
Girdled	125	52.0	19.2	0	0	16.8	12.0	16.8	0.526	0.340	10.60
Normal	92	71.7	0	0	0	10.9	7.6	9.8	.496	.311	.....
Defoliated	172	96.0	0	0	0	23.0	.6	1.2	.447	.300	9.50
Tree 44:											
Girdled	268	31.3	17.9	2.2	0	21.3	16.1	26.9	.562	.376	10.76
Normal	180	77.8	4.4	0	0	11.7	1.1	6.1	.488	.358	9.66
Defoliated	298	94.4	.3	0	0	3.0	1.3	1.0	.469	.321	9.67
Tree 134:											
Girdled	201	19.9	29.8	6.0	2.5	13.9	15.4	41.8	.597	.403	11.38
Normal	266	67.0	0	0	0	12.4	7.9	12.8	.592	.401	10.62
Defoliated	253	74.8	2.4	0	.4	6.7	6.3	11.9	.551	.370	10.32
Tree 135:											
Girdled	130	29.2	46.9	10.9	3.8	19.2	17.7	14.6	.596	.356	10.76
Normal	306	75.2	15.7	4.2	.7	4.2	2.3	.7	.474	.337	9.83
Defoliated	164	97.6	2.4	0	0	1.2	0	0	.445	.248	9.59
Tree 136:											
Girdled	337	31.2	42.2	13.9	2.4	20.2	10.7	20.2	.585	.310	10.02
Normal	293	68.6	19.1	1.7	1.0	8.9	4.1	3.8	.536	.315	9.04
Defoliated	350	90.9	4.3	.3	0	4.3	1.1	.9	.553	.298	9.18
Tree 151:											
Girdled	192	58.4	26.0	6.8	.5	13.0	6.2	5.7	.546	.353	9.95
Normal	191	91.7	0	0	0	4.7	2.6	1.0	.538	.295	9.28
Summary:											
Girdled	1,253	35.4	30.7	8.0	1.5	17.9	12.8	21.9	.569	.356	10.58
Normal	1,328	74.5	8.4	1.4	.4	8.4	4.1	5.2	.521	.336	9.69
Defoliated	1,247	89.3	2.1	.1	.1	3.8	2.0	3.0	.493	.307	9.65

The data presented in Table 6 reveal at once that there was a very wide variation in the extent of browning occurring in fruit from branches receiving the various treatments. Invariably the fruit from girdled branches showed the highest percentage of apples affected with internal browning and the lowest percentage of sound fruit. Not only is this the average condition, but it also holds for the fruit from each tree taken individually. The normal fruit, from untreated branches, was much better in keeping quality than that from the girdled limbs, while fruit from branches having about half the leaves removed was markedly better than the normal fruit. Thus, in fruit from the same tree the apples supplied with the

greatest quantity of carbohydrate, as obtained by girdling the branches and thinning the fruit, tended most to browning.

When the analyses presented in Table 6 are studied, however, it is evident that there is a considerable variation in the acid and sugar content of the fruit from different trees, without a corresponding variation in the extent of browning that developed. For example, even the fruit from defoliated branches from tree No. 134 was higher in sugar content than fruit from girdled or normal branches from either tree No. 151 or tree No. 136. Within the individual tree, the apples from the girdled branches, running high in sugar and acid as compared to normal for the tree, have shown a marked tendency toward browning, but there is no evidence to indicate that trees that normally produce fruit with high sugar content also produce fruit with a marked tendency toward browning.

The analyses presented in Table 6, considered in connection with other unpublished data on apple analyses, indicate that there may be a wide variation in the chemical composition of the fruit from different trees in an orchard and from year to year from the same tree. The results obtained by girdling and defoliating indicate that the browning of the fruit in storage is associated with conditions that produce high sugar and acid content for that tree, but not that trees normally producing fruit of high sugar and high acid content tend to produce fruit with a greater tendency to browning than trees that normally produce fruit of low sugar content. In fact, the evidence available at the present time indicates that the greatest tendency to browning occurs in trees which normally produce fruit of rather low sugar content.

From a consideration of the foregoing data, it appears to be established that internal browning of apples in storage results from certain conditions within the tree. These conditions are not fixed, in the sense of being constant or hereditary, for a tree may produce fruit that browns badly one year and be almost free from browning the year following. Rather than being a tree characteristic, browning of the fruit in storage seems to occur when certain conditions arise within the tree. The experiments on girdling and defoliating indicate that these conditions may be present in one part of the tree, being restricted to certain branches, while the fruit on the tree as a whole remains fairly sound. The fact that in these experiments sound apples were very often found in lots of fruit from a single tree, though in some cases almost the entire crop would be classed as affected with bad browning, indicates that the conditions that bring it about are even much more localized than the individual tree. The evidence accumulated during the course of these investigations gives strong indication as to what may be the conditions in the tree conducive to browning.

Direct evidence on this question is furnished by the very decisive results of thinning the fruit and girdling branches during the summer of 1919. The trees were bearing a heavy crop, and browning was almost negligible in normal fruit during the following winter storage season. Very considerable browning, however, appeared in the large well-nourished fruit from the girdled branches, whereas even less than the average appeared in fruit from branches from which half the leaves had been stripped.

With these facts in mind, before picking in 1920 and again at the time of picking, careful notes were made concerning the density and condition of the foliage on the trees, the size of the crop, and the size of the fruit. The crop in the orchard was light during the 1920–21 season, so the fruits as a rule were of very large size. Individual yields varied from practically no fruit to 6 or 8 boxes per tree. Since most of the trees under observation were very large, even a crop of 8 boxes was not more than an average yield for a normal year.

The foliage on the different trees varied widely in density and appearance. The size of the fruit varied with the size of the crop and the density and condition of the foliage. When the crop was small and the foliage was in good condition, the fruit was usually of large size.

Upon comparing these records with the percentages of browning that developed during the storage season, it was found that trees with the combination of good, rich foliage and a small crop of large-sized fruit have practically always produced fruit that tended to brown very badly. On the other hand, fruit from trees with a large crop of medium-sized apples has almost invariably developed very little browning. Trees possessing very poor foliage and also bearing a very light crop were often difficult to place so far as browning was concerned. Fruit from such trees usually developed moderate browning.

This relationship of the total crop on the tree to the occurrence of browning may be shown by a study of the trees in the nitrogen plat. Records on the fruit from trees of this plat, together with notes made at the time of picking in 1920, are presented in Table 7.

It is impossible to predict accurately from such data as the notes on tree conditions presented in Table 7 how much internal browning will develop during the storage season. It is of interest, however, that all the trees in the nitrogen plat which produced a high percentage of sound fruit are those producing a fairly large crop of medium-sized fruit. Nos. 133, 134, 137, and 138 were all well loaded for trees of their size. Trees Nos. 46, 132, and 136, fruit from which became particularly badly browned, had very light crops of large-sized fruit and excellent foliage.

TABLE 7.—*Extent of the internal browning of apples grown on the nitrogen plat during the season of 1920.*

Tree.	Remarks.	Yield (boxes).	Comparison of results (per cent).		
			Sound.	Medium and bad browning.	
				Tissue.	Core.
No. 44	Foliage good, tree medium size	5 to 6	14.8	22.2	38.8
No. 45	Foliage medium to poor	4	7.5	49.2	47.5
No. 46	Large tree, foliage good	4 to 5	4.0	77.0	78.0
No. 130	do	3	8.7	31.3	47.8
No. 131	Large tree, foliage medium	3	4.2	42.5	55.0
No. 132	Large fruit, foliage good	3	0	89.4	91.5
No. 133	Small tree, good foliage	4	43.6	7.4	13.5
No. 134	Medium tree, small fruit	8 to 10	30.9	19.1	21.3
No. 135	Large tree, foliage poor	1	0	47.4	56.6
No. 136	Large tree, foliage good	4	1.8	72.7	90.9
No. 137	Small tree, small fruit	7	44.3	6.1	11.5
No. 138	Very small tree, foliage good	3 to 4	40.7	21.2	8.9
No. 139	Foliage medium, fruit medium size	1½	5.8	25.3	36.8
No. 140	Small tree, foliage good	2	10.5	45.6	37.7

The prevalence of browning during the four years in which these records have been kept also bears out the relationship existing between internal browning and the crop on the trees. During the growing and storage season of 1917–18 the orchards under test in the Pajaro Valley proper had a very heavy crop of fruit, and inspection of many boxes of apples showed practically no browning present. The year following, 1918–19, the crop was very light, many trees yielding only 1 to 3 or 4 boxes, but the fruit was of large size. In that year considerable internal browning developed in storage, and undoubtedly only the fact that storage temperatures were held at 36° F. instead of lower prevented disastrous results. During 1919–20 another heavy crop was produced, and only traces of browning appeared in any of the lots except from branches that had been girdled during the growing season. The season of 1920–21 was another " off " year for the orchard, with small yields of large-sized fruit. Internal browning again was very prevalent in fruit stored at low temperatures, and the commercial crop was probably saved only by holding the fruit at temperatures ranging from 36° to 38° F.

It has often been noted in inspecting fruit for browning that the larger apples have a greater tendency to develop browning than the smaller sizes. It is recognized in the trade also that this tendency holds true. There are, however, many specific exceptions where small fruit will become badly browned and where large fruit, under similar conditions, will remain sound; but the average, particularly in fruit from the same tree, seems to greatly favor small fruit for soundness. This again bears out the apparent condition of browning developing largely in fruit grown under conditions of light crop and good leaf

area. Within a single tree the variation in size of individual fruits produced is undoubtedly due in general to variation in the nutritive supply to the different fruits. Heavily loaded or shaded branches will produce small fruit, while branches with good foliage and bearing very few apples will usually produce large specimens in comparison with the rest of the tree.

RÉSUMÉ OF FACTORS CONDUCIVE TO INTERNAL BROWNING.

There are a number of factors which undoubtedly contribute to bring about conditions in the fruit conducive to internal browning when that fruit is placed in storage. Unfortunately, most of these factors, other than storage temperature, are beyond the control of the fruit grower or handler. A résumé of conditions found to be associated with the tendency of Yellow Newtown apples to brown internally in storage is helpful, however, in giving the conditions toward which the orchardist should strive in order to reduce or eliminate this trouble. It is, perhaps, of greater importance that these data give a basis for a fairly accurate prediction of the probable percentage of browning that will develop in any crop. If conditions are right for the development of browning in the fruit, special precaution should be taken to prevent the storage of that fruit at low temperatures.

Internal browning has been most prone to occur in fruit from the lower portions of the Pajaro Valley, where conditions of low temperature and high humidity during the growing season are coupled with very fertile soil. The sunshine and the temperature and air humidity during the growing season are obviously beyond the control of the orchardist. While internal browning is not unknown in other apple-growing regions, it occurs to such a small extent that it is not of commercial importance. This indicates that apples from the Pajaro Valley differ from those from other sections in the tendency to brown internally in storage only in degree, and it is apparently the peculiar growing conditions in this valley which often produce rather large fruits of coarse texture that are responsible for the widespread tendency to browning.

Even in the Pajaro Valley, however, there are certain seasons in which very little browning develops in the fruit, and in seasons when browning does develop there are certain trees the fruit from which develops very little browning as compared to that from other trees about them. And even from trees most of the fruit of which shows bad browning certain apples will remain entirely sound in cold storage.

All these facts indicate that internal browning is due to some condition within the tree, probably nutritional, which affects the fruit. This condition may be very general, and a large percentage of

browning will develop in fruit from over the district as a whole, or it may be so limited that browning will be practically unknown commercially during certain seasons.

CONCLUSION.

During the four years in which the present investigators have been studying this trouble, it has been found that seasons of very high crop production have been practically free from internal browning. During years when browning was prevalent the fruit from trees producing very heavy crops has been relatively much more nearly free from the trouble than neighboring trees that produced light crops. On a single tree it has been possible, by heavy thinning and girdling of branches, to produce apples that tended to brown badly, while partial defoliation of well-loaded branches resulted in sound fruit. Heavy fertilization with manure tended to increase the percentage of browning, and heavy nitrogen fertilization increased browning markedly in all trees except those bearing a very heavy crop of fruit.

Apparently under the growing conditions of the Pajaro Valley fruit tends to brown internally in storage when light crops of large coarse-textured fruit are produced. It is impossible for the orchardist to control weather conditions, and it is not always possible to obtain a uniformly heavy crop on the trees. Internal browning apparently does not develop seriously, however, if storage temperatures are held at 36° F. or above. It is particularly important that storage conditions be right during years of light crops and large-sized fruit.

SUMMARY.

Certain varieties of apples when placed in cold storage for a long season develop a brown discoloration in the flesh of the fruit which has been designated "internal browning." This trouble is particularly serious in the Yellow Newtown apples grown in the Pajaro Valley district of California, where investigations have been carried on for a number of years.

This trouble is not caused by a parasitic organism but appears to be brought about by certain conditions within the fruit itself.

Apples from the Pajaro Valley have been found to be far more susceptible to this trouble than those from any other section of the country. This district has an extremely cool growing season, coupled with high humidity and fertile soil conditions.

Internal browning develops to a far greater extent in fruit held at 32° than that kept at 36° or 40° F. Its occurrence to an extent sufficient to be important commercially can be largely prevented by storing the Pajaro Valley apples at 36° to 38° F.

There is usually a sharp increase in the percentage of browning in the fruit following its removal from cold storage.

Internal browning develops mainly in those orchards having high soil fertility and located in the California coastal fog belt, where the humidity is high and there is little sunshine.

It has not been possible to produce internal browning in apples or to prevent its appearance by any one of several fertilizer treatments carried out in orchards during a period of four years.

Internal browning of apples varies widely in the fruit from individual trees during any single year, and a given tree does not produce year after year fruit tending to become browned when put in storage. Often a tree will produce sound fruit one year and fruit that becomes badly browned the year following.

Apples of large size, high in sugar and acid content, and from branches girdled during the growing season tended to become browned to a much greater extent than normal fruit from the same tree. Apples from branches partially defoliated showed markedly less browning than fruit from branches with normal foliage.

Internal browning develops mainly in apples from trees growing under the environmental conditions described during seasons when the crop on the tree is very light and the fruit tends to large size and coarse texture. When a heavy crop is produced, little internal browning seems to develop. With a light crop of large-sized apples, holding the fruit at 36° F. or above will prevent serious loss from this trouble in cold-stored Yellow Newtown apples.

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NATURAL REPRODUCTION OF WESTERN YELLOW PINE IN THE SOUTHWEST.

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PURPOSE OF THE STUDY.

A forest in which cutting is not followed by reproduction is doomed to ultimate extinction. In some regions planting or direct sowing will prove an efficient and economical means of restocking. In the western yellow pine forests of Arizona and New Mexico slow growth and high costs, as a general rule, render artificial reforestation impractical; therefore restocking must be accomplished by natural means. Because of the abundance and great economic importance of western yellow pine, the difficulties attending its natural regeneration present the most vital silvicultural problem in the Southwest. Young growth is abundant in many localities of this region; but in the localities of most extensive lumbering operations it is generally deficient, even where seed trees were left. The purpose of the study on which this report is based is to determine what measures are necessary to secure natural reproduction. Because the problem is particularly acute on the Coconino and Tusayan National Forests in northern Arizona, where several large mills have been in operation for 30 years, investigations have been concentrated there. Although these investigations do not cover every individual case which may be

encountered in the yellow pine type of the Southwest, they have sought to evolve broad principles which will serve as a basis for the solution of reproduction problems under a wide range of conditions.

REVIEW OF PREVIOUS INVESTIGATIONS.

In 1904 Leiberg (*14*)[1] wrote regarding western yellow pine on the San Francisco Mountains Forest Reserve, now the Coconino and Tusayan National Forests:

> Apparently there has been an almost complete cessation of reproduction over very large areas during the past 20 or 25 years, and there is no evidence that previous to that time it was at any period very exuberant. The low reproductive ratio is due to various causes, some depending on the operation of natural agencies, other on human intervention. Those originating in natural agencies manifest themselves chiefly in deficient seed production, a factor which strikes at the very root of existence of the species; those due to the acts of man depend on the destruction of the individual trees.

Natural reproduction of western yellow pine has been the foremost subject of investigation at the Fort Valley Experiment Station since the establishment of the station in 1908.[2] The initial results of this study were presented by the writer in 1909 (*15*). In the same year a series of sample plots was established on the Coconino and Tusayan National Forests for the purpose of maintaining continuous records of the progress of reproduction as well as of growth on areas cut according to the silvicultural practice then prevailing. In 1910 and 1911 additional plots were established on the Datil, Santa Fe, and Gila National Forests in New Mexico. In 1913 another series of plots, involving three methods of cutting, was established on the Coconino. The method of establishing the plots has been described in detail by Woolsey (*27*). A discussion of results obtained from records of the first five-year period on the Coconino and Tusayan plots was published by the present writer in 1918 (*18*).

The conclusions drawn from all of the studies by the Fort Valley Experiment Station up to 1918 are summarized in the following paragraphs. It should be noted that some of these conclusions, particularly with reference to forest cover, brush disposal, and grazing, have been modified and developed as a result of more recent investigations.

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[1] The italic figures in parenthesis refer to the bibliography in the back of the bulletin.

[2] Grateful acknowledgment is due to members of the staff of the Fort Valley Experiment Station. Among those who at different times have been identified with this study are H. D. Burrall, H. H. Greenamyre, J. S. Boyce, C. F. Korstian, E. W. Nelson, Hermann Krauch, and F. W. Haasis. Especially valuable assistance has been rendered by Mr. Haasis, who during the last two years has made most of the seedling counts, and has taken an active part in the soil studies and in the compilation of data. J. O. Veatch, of the Bureau of Soils, has made a most valuable contribution to this investigation through his soil surveys and other soil studies, all of which have aided materially in handling this phase of the reproduction problem.

In addition to insuring an adequate seed supply, it was considered important to retain trees enough to preserve forest conditions, since excessive opening up of the stand results in increased danger from wind, evaporation, and frost.[3] Recent studies have thrown much additional light on this phase of the problem.

Failure of reproduction was shown to be due less to poor germination than to high mortality during the first two or three years following germination. The high death rate among seedlings less than a year old was attributed largely to the fact that germination does not, as a rule, take place until July or August, and consequently the seedlings are still very tender at the end of the growing season. Records show that great numbers succumb as a result of droughts in September and October, that some are killed by early frosts, and that many are thrown out of the ground by frost heaving, which takes place late in the fall and early in the spring. Drought was found to take an additional toll in the dry foresummer of the second and third seasons.

The presence of brush and litter resulting from logging, if properly distributed, was found to favor reproduction by protecting young seedlings against drought and frost. Studies in 1920 have shown that this conclusion applies only under certain conditions.

Reproduction was observed to be better on the more or less gravelly or stony soils than on heavy clay soils which are largely free from gravel and stones. This was thought to be due to the greater permeability to moisture and plant roots resulting from the admixture of coarse materials.

Two insects, the tip moth and the white grub, or larva of the May beetle, were charged with an enormous amount of damage.

Examinations as early as 1908 showed excessive damage by sheep and indicated the advisability of excluding them during the period of reproduction. The conclusions were later corroborated by the more comprehensive study of Hill (*11*), whose investigation showed considerable variation in the amount of damage for different ages of seedlings, season and intensity of grazing, and character of forage. His work is more fully discussed in the chapter on grazing.

SUMMARY OF CONCLUSIONS IN STUDY UP TO 1918.

The status of the reproduction problem and the outlook on the Coconino and Tusayan National Forests, as viewed by the writer (*18*) in 1918, may be briefly stated as follows:

Adverse climatic conditions dominate the situation to such an extent that no system of silviculture can hope completely to solve the reproduction problem in this region. Dense, even-aged stands of seedlings

[3] Similar observations had been made by Plummer (*20*) in 1904.

become established only at long and irregular intervals, when a good seed crop is followed by two or more years of favorable climatic conditions. More dependable results can be secured by the slower process, in which a few seedlings are established every two or three years under average conditions of seed and moisture. On average sites, a sufficient number of seedlings will accumulate in two or three decades to establish a fairly good stand. It was believed that although silviculture could not hope to overcome the effects of adverse climatic conditions, it might ameliorate them by taking advantage of the protection afforded by standing trees, brush, and ground cover. Root competition had not been extensively studied at that time. Sheep were known to do serious damage to seedlings, but it had not been proved that the damage was sufficient to preclude reproduction; moreover, it was surmised that certain adverse sites, especially bunch-grass lands, would not restock with any degree of certainty even if sheep were excluded. What was needed to test the correctness of the above deductions was a concrete demonstration of results. No opportunity had been afforded for such a test. Thus, after the study had been carrier on for nine years, many of the conclusions were still open to question.

RECENT DEVELOPMENTS IN THE STUDY.

The year 1919 was an epoch-making one in the study of western yellow pine reproduction. Developments on a number of sample plots established in 1909 reached a point where it was possible to show distinct progress, and to prove by actual results that the cumulative process referred to above is effective. This development was anticipated, but the unforseen also happened. In 1918 the seed crop of western yellow pine over the entire Colorado Plateau was unusually abundant, and the summer rainfall in 1919 was the heaviest recorded in years. The result was a seedling crop which, considering area covered as well as density, has not been equaled during the 25 years in which the forests in this region have been under Forest Service administration. Thus we have in a single year a corroboration of both theories previously advanced in regard to the process of natural reproduction. Moreover, the abundance of seedlings presents an opportunity for a study of the factors influencing their establishment in a way which was not possible before.

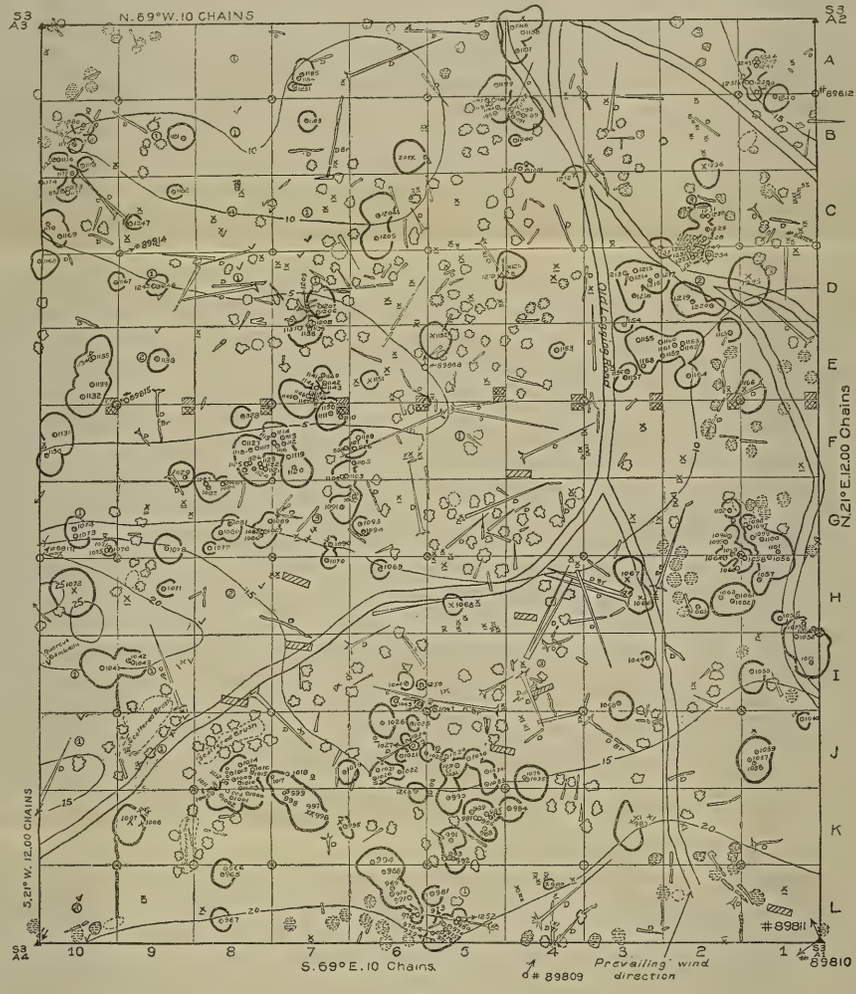
Most of the intensive studies have been made on the permanent sample plots previously mentioned. There are 29 of these plots on the Coconino and Tusayan National Forests. The area per plot ranges from 2 to 12 acres and their aggregate area is 120 acres. Each plot is mapped on a scale of 1 inch to the chain. The location of every tree above 4 inches in diameter, scattered saplings and groups of saplings below that diameter, logs, brush piles, and other features

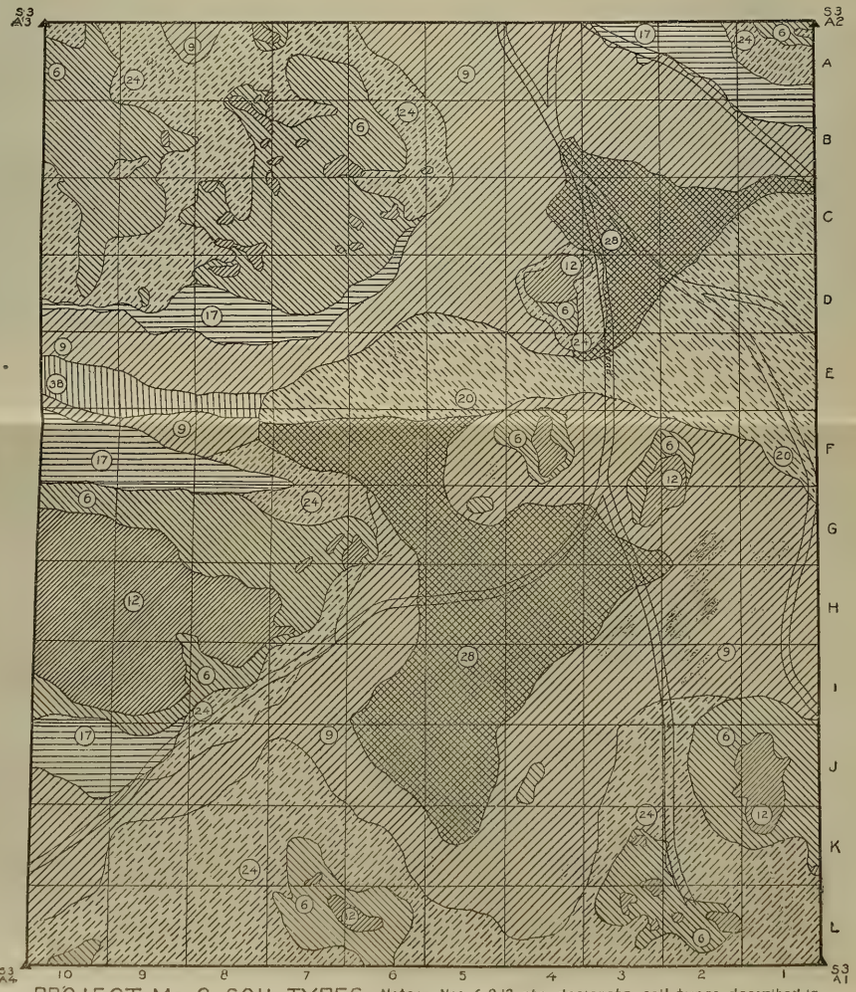
PROJECT Mc-2

Sample Plot S3-A, Tusayan National Forest
Location, S/2 ⅔ S/2 N/2, Sec. 24 T. 22 N. R. 5 E. G ⅔ S.R.M.
Plot established fall 1909, Logged summer 1909
Datum Plane 4 ch. S of S3-A3. Contour interval 5 ft.

- Black Jack
- Black Jack stump (Marks may be above or below)
- Dead Black Jack
- Yellow Pine
- Yellow Pine stump
- Dead Yellow Pine (Marks may be above or below)
- 1018 Tree number
- Felled tree
- Down tree or log partly burned or decayed
- Windfall, Letter D indicates tree was dead
- Br Tree broken off
- V Western Yellow Pine seedling 12" or over (Apex of V indicates location)
- Western Yellow Pine seedling 12" or over injured
- (3) Number of seedlings over 12" high and below 4" d.b.h. per square chain
- Brush pile
- Scattered brush
- Outline of tree crowns
- Set up Station
- 5X10 foot plot for seedling counts
- 5X10 foot denuded plot. Seedling counts
- #89717 Etc. Photograph (1909) Direction indicated by arrow
- Scattered brush burned
- Brush pile burned

0 1 2 3 CHAINS





PROJECT Mc-2-SOIL TYPES Note:- Nos. 6, 9, 12 etc. designate soil types described in text and indicated by various kinds of crosshatching

are indicated (Fig. 1). On smaller plots within the larger ones all seedlings have been marked with number tags since 1913, and their condition has, with a few exceptions, been recorded from one to three times each year. In addition to the reproduction studies, the diameter, height, and condition of each tree above 4 inches in diameter is recorded every fifth year.

Since repeated reference will be made to various plots in this bulletin, brief descriptions are in order.

DESCRIPTION OF SAMPLE PLOTS.

1A and 1B.—Established 1909; areas 6.4 and 10 acres, respectively; private cutting about 1894; seed trees 3 to 4 per acre; soil basaltic loamy clay, mostly stony; topography gently rolling; altitude 7,300 feet; ground cover moderately dense, mainly grasses, closely grazed by cattle and horses. Both plots are fenced against sheep. Plot 1A is almost completely restocked and plot 1B about half restocked with seedlings 5 to 25 years old.

2A and 2B.—Established 1909; areas 7 and 4.9 acres, respectively; private cutting about 1895; seed trees 6 to 8 per acre; topography gently rolling; altitude 7,300 feet; soil of volcanic origin, but decidedly more gravelly than on plots 1A and 1B. Both plots are fenced against grazing, but sheep and cattle graze all around them. Reproduction is almost complete, ranging from 5 to 30 years old.

3A and 3B.—Established 1909; areas 12 acres each; Forest Service cutting 1909, brush piled but not burned; seed trees 5 to 8 per acre (see Table 19); altitude 7,300 feet; topography gently rolling; soil heavy clay loam derived from basalt; ground cover heavy bunch grass, fenced, not grazed; sheep and cattle grazing outside. Both plots are somewhat more than half restocked with seedlings which have originated entirely since the plots were fenced 12 years ago; therefore they furnish a striking contrast with the surrounding areas which are almost destitute of reproduction. These plots are typical of the areas on which the reproduction problem is most critical. For this reason and because of their accessibility from the experiment station they have met the requirements of this study more fully than any of the other plots.

4A and 4B.—Established in 1909; areas 8 acres each; Forest Service cutting 1909, brush piled but not burned; soil mostly a stiff clay covered by volcanic cinders; topography gently rolling; altitude 6,800 feet; ground cover generally sparse, mainly grasses, lightly grazed by cattle and sheep, reproduction deficient. These plots represent the cinder region of the Coconino, which is of limited extent.

The annual precipication is about 24 inches on all the foregoing plots, except 4A and 4B, which probably receive 2 or 3 inches less.

In 1913 another series of areas was established for the purpose of comparing results under different methods of cutting. They are designated 5-I, 5-II, and 5-III. Seven sample plots of from 2 to 4 acres each were established within each area. The differences in method of cutting are described in the chapter on this subject (pp. 74–75). Soil and topography are similar to those of plots 3A and 3B, excepting that the soil runs shallower on the average. The altitude ranges from 7,200 to 7,400 feet. Herbaceous vegetation is moderately dense and was closely grazed by cattle and sheep up to the summer of 1919, when representative portions of each area were fenced. A few horses graze within the inclosures, but the outside is still open to cattle and sheep. Because of the comparatively short period which has elapsed since the establishment and fencing of these plots, and because of their distance (30 miles) from the experiment station, they have not been studied so intensively with respect to reproduction as some of the older plots near the station.

PROGRESS OF REPRODUCTION ON SAMPLE PLOTS.

The progress of reproduction on sample plots established in 1909, as shown in Tables 1 to 4, is characteristic of cut-over areas on the Coconino and Tusayan National Forests. Table 1 gives results of extensive surveys, including only seedlings 1 foot or more in height but covering the total area of 40 acres. Plots having considerable numbers of seedlings in 1909 are omitted. Table 2 shows the distribution of age classes for seedlings 3 years and over on plots 3A and 3B. This table is based upon a study covering 8 plots of 0.1 acre each within these two areas. Tables 3 and 4 concern primarily the small seedlings from 1 to 5 years of age. A study of these tables impresses one with the extreme slowness and uncertainty which characterizes the reproduction of western yellow pine in this region. The high infant mortality here indicated has been found to prevail generally during the entire period in which studies have been carried on. Time and again promising stands of young seedlings have been almost completely wiped out during the first or even the second season. The conclusion first drawn from these records was that nothing could come of the light seedling crops which usually appear every two or three years, and that the only way to secure reproduction was to wait for extraordinarily favorable conditions. This is probably true of plots 4A and 4B, because the cinder cover renders germination extremely difficult. Studies of age classes on areas which had made some progress in reproduction, however, gradually evolved the theory, first expressed in 1917, that, despite the almost complete disappearance of seedling crops in the early stages, enough will survive so that after about 20 years a given area if properly

protected would become fairly well restocked. Table 2 shows how this process has worked on plots 3A and 3B, which are typical of extensive areas on which reproduction is lacking.

TABLE 1.—*Record of seedlings 1 foot or more in height.*

[All seedlings counted on entire area.]

Plot.	Year established.	Year logged.	Area acres.	Number of seedlings.			Number per acre, 1919.
				1909	1914	1919	
3A	1909	1909	12	5	30	333	27.75
3B	1909	1909	12	0	15	375	31.25
4A	1910	1909	8	18	33	68	8.5
4B	1910	1909	8	57	179	204	25.5

TABLE 2.—*Number of seedlings by age classes, exclusive of 1919.*

[Based upon 8 plots of 0.1 acre each within plots 3A and 3B.]

Year of origin.	Age in years, 1919.	Number of seedlings.	Percentage of total.
1908–9	11–12	1	0.5
1910	10	10	4.7
1912 (or 1913)	8	28	13.2
1914	6	80	37.5
1916	4	76	35.7
1917	3	18	8.4
Total	.....	213	100.0

TABLE 3.—*Establishment of seedlings.*

[Total number of seedlings by age classes.]

Plot.	Number of 5 by 10 foot plots.	1909			1914			1915			1916		
		1 yr.	2–5 yrs.	Over 5 yrs.	1 yr.	2–5 yrs.	Over 5 yrs.	1 yr.	2–5 yrs.	Over 5 yrs.	1 yr.	2–5 yrs.	Over 5 yrs.
1A	8	0	3	0	2	2	2	0	4	2	[1] 1	2	3
1B	10	0	3	1	6	7	1	0	10	1	[1] 20	6	1
2A	7	0	0	0	5	5	0	0	6	0	[1] 6	4	0
2B	7	0	0	0	1	16	0	1	17	0	[1] 8	11	0
3A	10	0	1	0	34	0	0	0	3	0	[1] 0	2	0
3B	10	0	0	0	43	1	0	0	9	0	[1] 0	4	0
4A	8	0	1	0	0	0	0	0	0	0	0	0	0
4B	8	0	0	0	0	0	0	0	0	0	0	0	0

Plot.	Number of 5 by 10 foot plots.	1917			1919			1920		
		1 yr.	2–5 yrs.	Over 5 yrs.	1 yr.	2–5 yrs.	Over 5 yrs.	1 yr.	2–5 yrs.	Over 5 yrs.
1A	8	0 0	17	3	144	13	3	0	99	10
1B	10	0	21	1	988	9	1	0	150	4
2A	7	3	5	0	34	6	3	0	39	3
2B	7	0	15	0	22	11	3	0	22	5
3A	10	0	1	0	1,275	1	0	0	217	0
3B	10	0	2	0	998	0	2	0	131	2
4A	8	0	0	0	3	0	0	0	0	0
4B	8	0	0	0	17	0	0	0	1	0

[1] Counts made August, 1917. Some seeds apparently germinated after this count.

TABLE 4.—*Sample of individual seedling record (beginning in second year).*

G=Growing condition. Go=Growing but leader injured. ?=Doubtful. D=Dead. L=Living but not thrifty.

Seedling number, plot 1B.	1915	1916	1917	1918[1]	1919	1920	Seedling number, plots 2A and 2B.	1915	1916	1917	1918[1]	1919	1920
1615	G	G	G	.....	G	D	1807	G	G	G	.....	G	D
1616	G	G	G	.....	Go	G	1808	G	D	.....	.....	.....	.....
1617	Go	G	G	.....	G	G	1809	G	D	.....	.....	.....	.....
1618	G	G	G	.....	G	G	1810	G	Go	G	.....	G	G
1619	G	G	Go	.....	D	.....	1811	G	G	D	.....	.....	.....
1620	G	G	?	.....	D	.....	1812	G	D	.....	.....	.....	.....
1621	G	D	.....	.....	.....	.....	1813	G	G	D	.....	.....	.....
1622	G	D	.....	.....	.....	.....	1814	G	D	.....	.....	.....	.....
1623	G	G	G	.....	G	G	1815	G	D	.....	.....	.....	.....
1624	G	D	.....	.....	.....	.....	1816	G	G	G	.....	G	G
1625	G	D	.....	.....	.....	.....	1817	G	D	.....	.....	.....	.....
1639	.....	.....	G	.....	G	G	1829	.....	.....	G	.....	D	.....
1640	.....	.....	G	.....	G	G	1830	.....	.....	G	.....	G	G
1641	.....	.....	G	.....	G	G	1831	.....	.....	G	.....	L	L

[1] No record.

Up to 1914 very few seedlings survived the first season. Although no counts were made on these plots between 1909 and 1914, it is known that considerable numbers started in 1910 and 1912. In 1914 the first-year seedlings were abundant for the first time since the establishment of the plots, but the records on 5 by 10 foot plots (Table 3) showed a low survival. Even at the present time 20 of these small plots with an aggregate area of 1,000 square feet contain only 3 seedlings of sufficient size to warrant any hope of ultimate survival. Reducing these figures to an acreage basis, we have 130 seedlings, 4 and 6 years old, per acre. These figures are much lower than those obtained by extensive surveys in 1920, which showed an average of 222 seedlings per acre ranging from 4 to 12 years of age. This discrepancy is attributed to the fact that the 5 by 10 foot plots did not adequately represent the better sites. (See Table 10.) Although the area is still not fully stocked, the results show unmistakable progress. To those who are accustomed to thinking of reproduction in terms of thousands instead of hundreds of seedlings per acre, it should be explained that dense stocking, though desirable, is not necessary in western yellow pine. This subject will be discussed further in another section of this report. At any rate, the seedling crop which originated in 1919 promises to complete stocking. Counts in August, 1919, showed an average of about 60,000 per acre on these plots. In September, 1921, about 7,500 per acre survived. The chances are good for 20 per cent of these to become established. Ten per cent would prove ample, and a still lower percentage would suffice to satisfy the minimum requirements.

On the Datil National Forest results prior to 1919 were about the same as on the Coconino and Tusayan, but comparatively few seedlings started in 1919. On the Santa Fe National Forest, areas logged in 1910 are now almost completely restocked.

FACTORS INFLUENCING REPRODUCTION.

The problem of determining the effect of various factors upon reproduction has been a difficult one on the Coconino and Tusayan National Forests, for the reason that reproduction has proceeded so slowly and in such erratic fashion that relationships could not always be clearly seen. Causes could be studied in detail, but with the almost entire absence of positive, concrete effects the conclusions which could be drawn become largely abstract, not to say purely theoretical. Now that considerable numbers of seedlings have become established under conditions which are pretty well known, the problem is easier.

Success or failure is more or less directly related to a number of factors. These are (1) seed supply; (2) climate; (3) soil; (4) herbaceous vegetation; (5) cutting; (6) brush disposal; (7) grazing; (8) miscellaneous enemies, including fire, insects, and rodents.

SEED SUPPLY.

Although reproduction is dependent upon a great many conditions other than seed supply, the presence of a sufficient amount of seed properly distributed is an obvious prerequisite. Correlation of available data on seed crops with ages of seedlings now on the ground, for specific areas in the vicinity of the Fort Valley Experiment Station, shows that abundance of reproduction is at least in a broad way related to seed crops. (See Table 9.) As a rule, the greatest number of seedlings on the basis of both germination and survival originates from the heaviest seed crops. A notable exception was in 1909, when a good seed crop resulted in the establishment of very few seedlings. Unfortunately, no quantitative records of germination are available from 1910 to 1913. No germination occurred in 1915, 1918, and 1920, following years of no seed production.

Ordinarily there is no deferred germination of western yellow pine in this region; that is, germination almost invariably takes place during July and August of the first summer after the seed matures. This point is mentioned because in certain species, notably Douglas fir and western white pine in the Northwest, according to Hoffman (*12*) the seed may lie dormant for years, thus accumulating in large quantities which germinate when favorable conditions arrive, especially after cutting. Western yellow pine seed in the Southwest does not normally lie over, because under favorable conditions it germinates in from 10 to 20 days, and because the occurrence of summer rains, at a time when temperature is favorable, creates almost ideal conditions for germination over a continuous period lasting from 30 to 60 days. Only in one instance

during the past 12 years has deferred germination been observed. In the summer of 1912 several plots were heavily seeded artificially with western yellow pine. The summer rains of that season were unusually light and irregular, with the result that on plots which had received little or no soil preparation very few seedlings appeared. A number of small plots were screened to exclude rodents. During the summer of 1913, when the rains were abundant, seedlings sprang up on these plots in such numbers as to prove beyond a doubt that the majority must have come from seed which failed to germinate the preceding season.

AMOUNT OF SEED REQUIRED.

Studies aiming at a quantitative determination of the amount of seed required to secure a satisfactory stand of seedlings have not succeeded in fixing absolute standards, because of the extreme variations encountered on different sites and in different seasons. The greatest variable is rainfall. In unfavorable years no amount of seed will bring results. In seasons when growing conditions are normal or above normal, germination is good if seed is present, and usually there is some survival.

One of the most direct and obvious factors in seed supply is the consumption of seed by rodents. The effective seed supply is that which is preserved until moisture and temperature conditions are such that germination can take place. In years of light seed production chipmunks and mice probably destroy almost the entire crop, but in good seed years a considerable amount remains unconsumed. This surplus is what counts in natural reproduction. It would be of interest to know to what extent the number of seed-eating animals fluctuates from year to year in relation to the pine-seed crop. It can scarcely be assumed offhand that failure or near failure of the pine-seed crop for two or more years will result in starvation of these animals, since they undoubtedly find a considerable source of food in the seeds of herbaceous plants. It does, however, seem safe to assume that if large crops of pine seed were produced over an extensive area annually, the seed-eating animals would increase to the limit of the food supply, and that therefore the frequent occurrence of short seed crops tends to hold these pests in check.

In attempting to fix a minimum limit of seed requirement, it must be borne in mind that in average years from 90 to 99 per cent of the seeds will be lost either through failure to germinate or through infant mortality. It is estimated that on the plots under observation near the Fort Valley Experiment Station during the nine years prior to the heavy seed crop of 1918, not more than one out of every thousand germinable pine seeds produced a seedling which lived beyond the age of 5 years. Present indications are that the 1918 seed

crop, because of the extraordinary moisture conditions in 1919, will yield much higher returns, possibly as high as 5 per cent and probably not less than 1 per cent. This should result in complete restocking on areas which were well seeded. Heavy crops may fail to give results, because they are not followed by suitable climatic conditions, and likewise a period of favorable climatic conditions may be wholly or partly ineffective, because it was not preceded by a good seed crop. Although the right combination, such as was experienced in 1918 and 1919, appears to be purely a matter of chance, we should aim to take advantage of such opportunities whenever they come. The minimum seed supply, therefore, should be the amount required to stock an area completely in one year under favorable climatic conditions. Using experience in broadcast sowing in this country and in Europe as a guide, and considering the many adverse conditions encountered in this region, we may fix this amount somewhat arbitrarily at 8 pounds per acre.

NUMBER OF SEED TREES REQUIRED.

The next question is, How many trees per acre are needed to produce the required minimum amount of seed? Because of the great variation in yield of different trees and the fluctuations from year to year, it is difficult to answer this question satisfactorily. Estimates should be based upon yield in good seed years.

YIELD OF SEED IN VIRGIN STANDS.

Table 5 shows the average yield and germination of seed from trees of various sizes and descriptions in virgin stands for 1909 and 1913. Both of these seed crops were classed as "good." Unfortunately the influenza epidemic in 1918 prevented securing data from the heavy crop of that year. Estimates based upon a few trees, however, indicate that the production was two or three times that of an average "good" seed crop. Within the area of the heavy seed crop in 1918, the yields are estimated to range from 15 pounds per acre on Forest Service cutting to as high as 30 pounds in virgin stands. In all collecting operations the cones were gathered from trees felled in logging. Since the cones usually begin to open within 10 days from the time the seeds are mature enough to collect, considerable difficulty has been experienced in securing seed from a sufficient number of trees to form a reliable basis for comparison. This applies particularly to blackjack,[4] because, being immature, these trees form a small proportion of the total cut in a logging operation on National Forest lands. One hundred trees were represented in each of the 1909 and 1913 collections.

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[4] "Blackjack" is a name locally applied to immature, dark-barked trees. The older, yellow-barked trees are called "yellow pine."

TABLE 5.—*Seed production in relation to character of tree.*

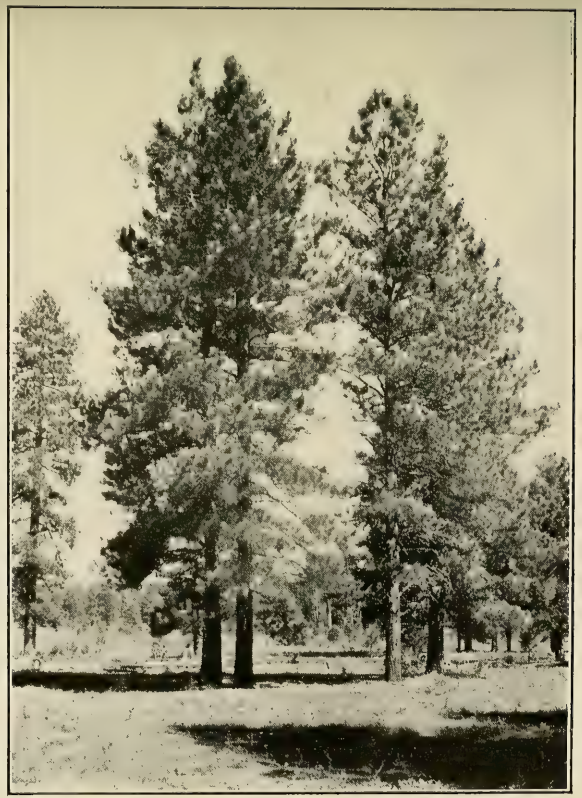
Character of tree.	Pounds of seeds per tree.		Percentage germinating in 35 days.		Number of seeds per pound, 1913.	Reproductive value,[1] 1913.	Average diameter breast-high, 1913.	Number of trees used as basis.	
	1909	1913	1909	1913				1909	1913
Yellow pine:[2]							*Inches.*		
Normal trees	2.16	1.07	64	83	14,300	12,700	24.6	36	49
D. b. h. below 18 in	.....	.44	.....	82	15,200	5,500	16.9	.....	4
D. b. h. 18–24 in	.....	1.19	.....	84	14,300	14,300	21.9	.....	19
D. b. h. 25–30 in	.....	1.37	.....	82	14,600	16,400	27.9	.....	19
D. b. h. over 30 in	.....	1.28	.....	83	13,100	13,900	33.6	.....	7
Abnormal trees:									
Spike-top	1.08	.79	79	88	14,600	10,100	25.3	7	4
Basal burn	2.52	.61	79	79	14,700	7,100	23.9	15	5
Heart rot	2.52	1.61	67	82	14,700	19,400	24.7	10	12
Suppressed	.48	.18	53	83	13,500	2,000	13.9	4	4
Mistletoe—									
Heavy	.....	.39	.....	82	16,400	5,200	18.9	.....	8
Light	.....	1.90	.....	81	14,600	22,500	27.0	.....	8
Blackjack, above 12 in	.....	.....	.....	.....	.....	.....	19.1	.....	9
Normal	1.20	.93	78	81	14,500	10,900	20.1	20	6
Mistletoe	.50	.58	51	78	14,700	6,700	14.7	3	3

[1] Reproductive value is the number of germinable seeds per tree.
[2] "Yellow pine" are mature trees usually over 200 years old; "blackjack" immature, usually below 200 years.

The data secured from the 1909 collection were analyzed in Forest Service Circular No. 196 (*16*). Although the main conclusions have been confirmed in a general way by the 1913 data, it may be seen from the table that the relation between normal and abnormal trees of various classes is more or less inconsistent. This is attributable in some instances to insufficient data. In other intances, as in the case of basal burn and heart rot, it is doubtful whether the physiological functions are materially affected, excepting in extreme cases. Since diseased and defective trees are, as a rule, removed from the stand for silvicultural reasons, a knowledge of their reproductive capacity is of only secondary importance in dealing with cut-over stands. It is sufficient here to state that diseased, defective, and over-mature trees do produce seed somewhat in proportion to their active crown area, and that the seed is not of appreciably inferior viability. The main objection to leaving such trees is that they deteriorate rapidly and are carriers of disease which may be transmitted to the future stand. Seed trees infected with mistletoe are especially objectionable, because the mistletoe spreads to young trees. Light or moderate infection does not seem to interfere seriously with seed production, but heavy infection greatly reduces the yield and probably the viability of seed. The most important principle to be borne in mind is that, other things being equal, the capacity of a tree to produce seed is determined by effective leaf surface, and that anything which tends to reduce the size of the crown or its efficiency as a food laboratory ultimately reduces the quantity and possibly also the quality of seed.

F—160229

FIG. 1.—IN FOREGROUND, A GOOD YELLOW PINE SEED TREE, 27 INCHES IN DIAMETER; IN BACKGROUND, A GROUP OF IMMATURE BLACKJACKS, 10 TO 16 INCHES IN DIAMETER, POOR SEED BEARERS; AT RIGHT, A DECADENT YELLOW PINE OF LITTLE VALUE FOR SEED PRODUCTION.



F—160241

FIG. 2.—GROUP OF THRIFTY BLACKJACKS, 18 TO 22 INCHES IN DIAMETER, WHICH YIELDED 1½ POUNDS OF SEED PER TREE IN 1918.

F—161982

FIG. 1.—HEAVY CONE LITTER UNDER THE LARGE YELLOW PINE SHOWN IN THE FOREGROUND OF PLATE I, FIG. 1.

F—160231

FIG. 2.—LIGHT CONE LITTER UNDER THE GROUP OF SMALL TREES SHOWN IN THE BACKGROUND OF PLATE I, FIG. 2.

Yellow pines bear more seed than blackjacks, because of their greater size and because their greater height gives them better exposure to sunlight. (Pl. I.) Individual trees in the blackjack class may produce as much as yellow pine, but the average yield for blackjack is brought down by the great number of nonproductive small trees. In the yellow-pine class yield rises steadily with diameter up to about 30 inches. Beyond this point it seems to fall off slightly, probably because of declining vigor. Unfortunately, sufficient data are not available to compare blackjacks of various diameters. Observations indicate that the trees below an approximate limit of 20 inches are relatively ineffective seed producers. This is not due wholly to immaturity, but also to the fact that, even after cutting, trees below this size are often dominated by older ones. The great majority of blackjacks occur in groups of considerable size. Under these conditions cones are borne in appreciable quantities only at the tips of branches which are exposed to sunlight. Germination tests have, as a rule, given somewhat higher values for blackjack than for yellow pine, although 1913 was an exception.

The average yields in 1909 and 1913, as shown by Table 5, were 1.61 pounds for yellow pine and 1.06 pounds for blackjack. These yields apply to normal trees above 11 inches in diameter in virgin stands. The question immediately arises as to whether they apply to stands *after* cutting. Removing trees of poor crown development and giving more sunlight to those left would tend to raise the average production. This is undoubtedly true of yellow pine, because all the trees of this class which are left are selected with special reference to crown development. Blackjack, however, is left, regardless of crown development, excepting for the removal of diseased or defective specimens. Blackjacks benefit from the elimination of root competition and to some extent from the removal of the shade cast by older trees; but blackjack groups are not, as a rule, opened up sufficiently to influence seed production.

YIELD OF SEED IN CUT-OVER STANDS.

Investigation of the method followed in gathering the data in 1909 and 1913 reveals the fact that cones were collected only from such trees as promised a sufficient yield to justify the work. This applies especially to the 1909 collection. Thus, the trees bearing no cones or very small quantities are not represented, and, therefore, an average for all trees as they occur in a stand would be lower than the above figures. In 1913 a survey by Krauch of an area logged the same year under Forest Service supervision showed that out of a total of 761 trees 12 inches and over in diameter, the respective percentages classed by ocular estimate as bearing good, light, and no seed crop were 38, 25, and 37. In other words, although the crop

for the stand as a whole was classed as good, only 38 per cent of the trees actually bore a good seed crop. Table 6 gives the results of similar surveys near Fort Valley in 1918 and 1921 on four plots, from 10 to 25 years after cutting. This table confirms the common observation that the smaller blackjacks, especially in large groups, bear very little seed. Undoubtedly the 1909 and 1913 figures are at least 50 per cent too high for blackjack. Yellow pine, however, is not subject to the same reduction, because the yellow pines left for seed are selected for this purpose and are therefore better seed trees than the average yellow pine in a virgin stand. Although the records in Table 6 are valuable as a general indication of seed production, they are inadequate as an expression of yield. What is needed is an actual measure of cones and germinable seed for each tree. Accurate data of this character can be secured only by collecting the cones from each tree, preferably after it is felled. Such an investigation is entirely feasible and should be carried out at the first opportunity.

TABLE 6.—*Seed production in relation to diameter of trees.*

Plot.	Diameter.	Total number of trees.	Percentage of trees in each yield class.							
			Very light or none.		Light.		Medium to good.		Heavy.	
			1918	1921	1918	1921	1918	1921	1918	1921
	Inches.									
1A	8–11	14	86	93	14	7	.....	.....	.....	.....
	12–15	27	33	37	56	48	11	15	.....	.....
	16–20	42	9	9	55	53	29	36	7	2
	21–25	28	.....	.....	50	61	32	29	18	11
	26–30	1	.....	.....	100	100	.....	.....	.....	.....
Total		112	.....	.....	.....	.....	.....	.....	.....	.....
Average			22	24	50	48	21	24	7	4
1B	8–11	4	100	75	.....	25	.....	.....	.....	.....
	12–15	5	60	60	20	40	20	.....	.....	.....
	16–20	22	14	14	45	45	36	41	5	.....
	21–25	18	.....	6	22	38	50	56	28	.....
	26–30	10	.....	.....	10	20	50	70	40	10
	Over 30	6	.....	.....	.....	17	67	50	33	33
Total		65	.....	.....	.....	.....	.....	.....	.....	.....
Average			15	15	25	35	42	45	18	5
3A	8–11	64	70	90	25	9	5	1	.....	.....
	12–15	70	31	41	50	42	16	17	3	.....
	16–20	45	13	15	31	36	45	49	11	.....
	21–25	41	3	10	39	27	34	58	24	5
	26–30	8	.....	.....	25	25	62	75	13	.....
	Over 30	12	8	17	17	8	33	75	42	.....
Total		240	.....	.....	.....	.....	.....	.....	.....	.....
Average			31	41	35	27	24	31	10	1
3B	8–11	28	71	82	25	18	4	.....	.....	.....
	12–15	70	37	44	49	46	10	10	4	.....
	16–20	86	19	22	37	55	38	23	6	.....
	21–25	77	8	10	27	47	53	43	12	.....
	26–30	15	20	20	20	53	60	27	.....	.....
	Over 30	2	.....	.....	.....	.....	.....	100	100	.....
Total		278	.....	.....	.....	.....	.....	.....	.....	.....
Average			26	30	35	46	32	24	7	.....

NOTE.—Nearly all the trees below 20 inches are blackjack, and nearly all above 30 inches are yellow pine.

In the absence of adequate data on yield, the solution of this problem has been approached by estimating the quantity of cones on the ground. The bulk of the cones fall on a fairly regular area almost directly under the crowns. (Pl. II.) The product of trees growing singly can readily be distinguished from that of their neighbors; but where several trees stand in a group the group must be treated as a unit. Most accurate results can be obtained by counting all of the cones on the ground; but since this procedure is very time-consuming, an approximation obtained by counting the cones on measured plots and thus calculating the number on the entire area has been considered reliable enough for certain comparisons. If the examination is made at the proper time, the cones of the latest crop can be distinguished from those of previous ones; but if the examination is delayed until all of the cones have become weathered, confusion is likely to arise. In the latter case a count of all the cones on the ground gives a comparison covering an indefinite period of years. If data are available on the number of cones required to produce a pound of seed, cone yields may be converted into seed yields. Since the factor varies in different years and for different trees, it should be applied with a clear understanding of its limitations. According to studies in 1913, the number of cones required for a pound of seed is 326 for yellow pine and 325 for blackjack.

On a cut-over area about 20 miles south of Flagstaff it was determined by the method described above that from four to six blackjacks above 11 inches diameter breast high, as they usually occur in groups, are required to produce as much seed as a single free-standing yellow pine. In one instance, which is fairly typical, there were 19 blackjacks in a single group. The diameters were distributed as follows: 11 to 15 inches, 11 trees; 16 to 20 inches, 5 trees; 21 to 26 inches, 3 trees. An area of 4,600 square feet was covered by cones, and the total number was calculated at 5,960, or an average of 314 per tree. Judging by the relative density of cone litter under various trees, it is evident that fully half of the total cone production of this group should be credited to about four of the largest trees. No attempt was made to separate the last crop (1918) from preceding ones. A good crop is known to have been borne in 1913, but only two light crops occurred between 1913 and 1918. It is believed that all the cones antedating 1913 and probably most of the 1913 crop were eliminated by decay.

About 200 feet from the above group was a single yellow pine 30 inches in diameter and of good crown development. A survey of the cone litter gave a total of 1,950 cones for the same period as that involved above. In other words, this tree produced as many cones as 6.2 blackjacks from 1913 to 1918.

In studies at the Fort Valley Experiment Station only the cones produced in 1918 were considered. A group of eight blackjacks ranging from 12 to 16 inches in diameter showed an average yield of 135 cones per tree for the 1918 crop. A single blackjack near by, 22 inches in diameter, yielded 500 cones. An open group of five blackjacks ranging from 18 to 22 inches in diameter showed an average production of 520 cones per tree. In the last two instances the heavier yield, as compared with the first group, is attributed to the larger size of the trees and better exposure to sunlight.

A full-crowned yellow pine 27 inches in diameter and about 100 feet high, standing in an open space a short distance from the first group of blackjacks mentioned above, yielded 3,500 cones in 1918, equivalent to 10.7 pounds of seed. The mass of half-decayed cones around this tree indicates that its cone production in past years must have been enormous. Within 100 yards of this tree are two yellow pines, 29 and 32 inches in diameter, whose combined yield in 1918 is calculated at 4,200 cones.

A fact which has been forcibly demonstrated by the cone survey is that it takes large trees to produce quantity of seed. Trees below 20 inches in diameter growing in the open often give the impression of being large seed producers, but an actual measure of their crop will show that their yield is but a small fraction of that of a similarly situated large tree.

The cone survey also indicates that large blackjacks are, as a rule, less productive than yellow pines of the same diameter. This is probably due to the fact that a yellow pine is usually much taller than a blackjack of equal diameter.

According to the foregoing comparisons, yellow pine has a seed-producing value about six times as great as that of blackjack. Considering, however, that yellow pine is a greater risk than blackjack, with reference to windfall, lightning, and general deterioration, a ratio of 5 to 1 is believed to be more reliable. After making due allowance for all factors which have been mentioned, the following have been adopted as conservative figures for yields on Forest Service cuttings in average seed years: Yellow pine, 2½ pounds per tree; blackjack, one-half pound per tree. These figures are admittedly crude and should be replaced as soon as possible by data based on actual yields in cut-over stands, but it is believed that their use is warranted in preference to a mere guess.

Using the preceding figures as a basis for calculations, the requirements for an adequate seed supply are 3 or 4 yellow pines or 16 blackjacks over 11 inches diameter breast high per acre. Stands of either pure yellow pine or pure blackjack are, however, rarely encountered. The usual practice on Forest Service lands is to leave

all sound, healthy blackjacks, aside from a few removed in thinnings, and in addition as many yellow pines as are needed to insure adequate seed production. If 8 blackjacks are left, 2 yellow pines will complete the seed requirements; if only 4 blackjacks are left, 3 yellow pines are needed. It will probably be necessary to modify this scheme to meet special conditions. Thus, when all the blackjacks are small, say below 15 inches in diameter, and closely grouped, the number of yellow pines should be increased. If the blackjacks are large and in open arrangement, the number of yellow pines might be decreased. It is suggested, as a tentative rule, that when the blackjacks over 20 inches in diameter exceed three per acre, those in excess of this number be classed (from the standpoint of seed production) as yellow pine.

Foresters of long experience with western yellow pine stands have observed that some trees seem to be naturally more prolific than others of similar size and external characteristics. Good seed bearers are recognized by the presence of great accumulations of old cones around their bases. Often the remains of three or four good cone crops can be identified. Absence of either old or recent cones is taken as an indication of low productiveness. In order to check these observations, the seed records of several sample plots have been examined. On four plots near the Fort Valley Experiment Station, an ocular estimate of the seed crop for each tree has been recorded annually since 1912. About 800 trees are included in this record. During these nine years many of the larger trees have produced four good cone crops, while other trees of similar size and development have produced no good crops. In many instances the difference in production can be accounted for by a difference in exposure to sunlight, or the presence of disease or injuries, but often no differences of this kind are apparent. In making these comparisons, only trees of apparently good vigor, good exposure to sunlight, and of a diameter above 20 inches have been considered. The high diameter limit was adopted with the idea of excluding trees which may not have come into full bearing on account of immaturity. On Plot 3A, out of a total of 59 trees falling within the above specifications, 17 per cent have produced four good crops, 20 per cent three, 29 per cent two, 20 per cent only one, and 14 per cent have borne no good cone crops during the nine years from 1913 to 1921, inclusive. The other plots show a similar relationship.

Table 7 shows the individual records of a number of representative trees on Plot 3A. A similar table could be prepared for each of the other plots. These records point unmistakably to the existence of individual variation. A longer period of observations might show

that some of the older trees in Group 3 were formerly more productive and that they are slowly declining. The blackjacks in Group 2 appear to be rising. This is probably a response to the increased light after cutting. Although it is not proved that the variations in seed production are inherent, we know that important differences do exist. Mature trees which show no signs of active cone production have little chance to become more productive as a result of cutting, and should therefore be discriminated against in selecting seed trees. Immature trees, on the other hand, may improve under the influence of increased light and moisture after cutting. Other things being equal however, preference should be given to those individuals which have the best record of past performance, as indicated by cones on the trees or at their bases.

TABLE 7.—*Sample record of seed crops for individual trees.*

[H=heavy, G=good, M=medium, L=light, VL=very light, O=none.]

Tree No.	Diameter breast-high, 1919.	Blackjack or yellow pine.	Seed crop by years.								
			1913	1914	1915	1916	1917	1918	1919	1920	1921
GROUP 1.—GOOD SEED PRODUCERS.											
968	26	Blackjack	G	O	L	O	O	H	O	O	G
970	25	do	G	O	L	O	O	H	O	O	G
996	24	Yellow pine	G	O	L	O	O	H	O	VL	G
997	31	do	G	O	L	O	O	H	O	VL	G
1007	32	do	G	O	M	VL	O	G	O	O	M
1037	25	Blackjack	G	O	M	M	O	H	O	VL	H
1041	32	Yellow pine	H	O	M	VL	O	M	O	VL	G
GROUP 2.—INTERMEDIATE SEED PRODUCERS.											
991	22	Blackjack	L	O	O	VL	O	L	O	O	G
1000	22	do	L	O	O	O	O	L	O	O	G
1035	27	do	L	O	O	O	O	G	O	O	G
1056	21	do	O	O	O	O	O	G	O	O	M
1131	32	Yellow pine	L	O	O	L	O	H	O	O	L
GROUP 3.—POOR SEED PRODUCERS.											
1026	23	Blackjack	L	O	O	VL	O	M	O	VL	L
1051	21	do	O	O	O	O	O	L	O	O	L
1066	32	Yellow pine	L	O	O	O	O	L	O	VL	M
1068	24	do	L	O	O	O	O	VL	O	VL	L
1132	25	Blackjack	L	O	O	O	O	L	O	O	L
1151	21	Yellow pine	L	O	L	O	O	VL	O	O	VL
1186	23	Blackjack	O	O	O	O	O	L	O	O	L

DISTRIBUTION OF SEED.

Next in importance to quantity of seed is distribution. The densest seeding takes place within a radius of 20 feet from the trees. The real test of the efficiency of the seed trees on a given area is made by determining the density of seeding in the more remote

parts of the larger openings. Openings depend not only upon the nearest seed trees along their borders, but upon all of the trees for several hundred yards around. In high winds, yellow-pine seeds may be carried as far as a quarter of a mile, but this is unusual. Since the prevailing wind direction is from south to southwest, one would naturally expect broader dispersal, but not necessarily denser seeding, on the north side of a seed tree. This, however, is not a matter of importance in a forest where seed trees occur on every side. What would be more valuable is a study of dissemination throughout a stand. The nearest approach to such a study is a seedling survey on sample plot 3A in September, 1919. Ordinarily the results of such a survey would not be a good index to seed dissemination, but in this case it is thought to be fairly reliable, for the reason that the rains during the summer of 1919 were so persistent that seeds germinated everywhere, even on logs. The seedling survey has an advantage over a seed survey in that it presents the results in a more advanced stage. Table 8 shows that in a heavy seed year the ground in Forest Service cuttings is abundantly seeded at distances of 100 to 150 feet from the nearest seed trees. (See also Fig. 1 for location of plots.) In other words, as far as seed supply is concerned, it is permissible to make openings from 200 to 300 feet in diameter if they will be surrounded by a large number of good seed trees. It should be borne in mind, however, that these plots represent optimum conditions with respect to both the number of seed trees and conditions for germination.

From the standpoint of seed dissemination as well as seed production, the ideal arrangement would be to space the seed trees as evenly as possible over the entire area. Since the trees often occur in groups to begin with, the ideal distribution can seldom be attained. Nevertheless, the importance of location should not be lost sight of. Other things being equal, a seed tree standing in the middle of an opening is several times as effective as one standing in a large group.

FREQUENCY OF SEED CROPS.

Table 9 gives a record of seed crops and their results on sample plots 3A and 3B, from 1909 to 1921. During this period three crops were classed as "good" and one as "heavy," and in six of the years there was little or no seed. According to this record prolific seeding occurs only once in three to five years. It is noteworthy that no seed was borne in the years following the good crop of 1913 and the heavy crop of 1918. No definite record is available for the year 1910, following the god crop in 1909, but it is known that a good yield did not occur.

TABLE 8.—*Distribution of first-year seedlings with reference to seed trees.*

A.—INDIVIDUAL PLOTS ON AREA 3A, AUGUST, 1919.

GROUP 1.

Natural plots 5 by 10 feet.	Distance [1] and direction of nearest seed trees.[2]	Number of seedlings per square foot.	Cultivated plots 5 by 10 feet.	Distance [1] and direction of nearest seed trees.[2]	Number of seedlings per square foot.
E-1	40 feet W., 50 feet E.; sun	1.22	F-1	40 feet W., 50 feet E.; sun	0.46
E-2	0 foot E., 35 feet NW.; sun	3.70	F-2	0 foot E., 35 feet NW.; sun	2.76
E-3	25 feet N., E., W.; group; sun	2.04	F-3	30 feet N., E., W.; group; sun	1.32
E-4	35 feet N. and E.; sun	1.60	F-4	40 feet N. and E.; sun	.28
E-5	60 feet N. and E.; sun	.42	E-5	55 feet N. and E.; sun	.62
E-6	40 feet N., 65 feet W.; group; sun	1.34	F-6	45 feet N., 65 feet W.; group; sun	.88
E-7	5 feet W.; group; shade	3.84	F-7	5 feet W.; group; shade	8.44
E-8	10 feet S., E., and W.; group; shade	5.20	F-8	10 feet S., E., and W.; group; shade	8.68
E-9	40 to 60 feet, all around; sun	1.44	F-9	40 to 60 feet, all around; sun	1.12
E-10	5 feet W.; group; part shade	4.70	F-10	5 feet W;. group; part shade	3.00

GROUP 2.

Natural plots 5 by 20 feet.	Distance [1] and direction of nearest seed trees.[2]	Number of seedlings per square foot.
F-4	100 to 125 feet, all around; sun	0.51
H-4	50 feet W.; 80 feet E.; sun	.99
I-4	50 feet E., 70 feet S.; sun	.73
J-4-5	10 feet S.; group; shade	4.62
L-1	100 to 125 feet, all around; sun	.44
H-7	30 feet N. and NE.; group; sun	1.22
I-7	75 to 100 feet, all around; sun	.45
I-8	40 feet S.; group; sun	1.04

GROUP 3.

Natural plots 5 by 20 feet.	Distance [1] and direction of nearest seed trees.[2]	Number of seedlings per square foot.
22	20 feet N.; group; sun	1.85
23	100 feet SW., 120 feet SE.; sun	.60
24	120 feet W. and S.; sun	.37

[1] Distances measured to edge of crown. [2] Location of plots and trees shown in figure 1.

B.—SUMMARY BY AREAS.

Designation of area.	Basis number of plots.	Number of first-year seedlings per square foot at various distances from seed trees.				Character of stand.
		0 to 25 feet.	25 to 50 feet.	50 to 100 feet.	100 to 150 feet.	
1B	10	2.35	1.32		0.40	Old cutting.
3A	21	2.53	1.30	0.78	.48	Forest Service cutting.
3B	12	2.32	1.51	.91	.41	Do.
6	10		3.30			Virgin.

NOTE.—All plots receive at least half of full sunlight; all on level sites.

TABLE 9.—*Frequency of seed crops and their relation to reproduction (sample plots 3A and 3B).*

Year.	Seed crop.	Number of seedlings per acre in 1920.[1]	Year.	Seed crop.	Number of seedlings per acre in 1920.[1]
1909	Good	0.5	1916	Light	8.4
1910	No record	4.5	1917	None	0
1911	Light	13.2	1918	Heavy	10,000
1912	Fair	0	1919	None	0
1913	Good	37.0	1920	Very light	0
1914	None	0	1921	Good	
1915	Fair	35.0			

[1] Number surviving in 1920, whose origin is credited to the seed crop indicated on the same line.

Records for other areas in the same vicinity are similar to, though not identical with, those in Table 9. When a good seed crop occurs generally over a region there is usually some seed everywhere, but the yield is likely to be much heavier on some specific areas than on others. This relation was strikingly brought to the author's attention in 1919, when the open cones of the heavy crop of 1918 still remained on the trees or were readily distinguishable on the ground.[5] In the region west and a few miles north of the Fort Valley Experiment Station the crop was the heaviest within the memory of forest officers in this region. Only 2 miles east of the station, however, the yield was very noticeably lighter. About 3 miles north, approaching the San Francisco Mountains and the upper limits of the yellow-pine type, the production was classed as light. South and southeast of Flagstaff it ranged from fair to good, but west and southwest it was heavy. In the cinder region, about 15 miles east of Fort Valley, the crop was very light. In 1920 practically no cones were in evidence in the region west of Fort Valley, where heavy yields were recorded in 1918; but in the cinder region east of Flagstaff, where only a very light crop was recorded in 1918, a fairly good crop occurred in 1920.

In some instances it is possible to account for these variations. It is known, for instance, that cone weevils figured prominently in the failure of the seed crop in the cinder region in 1918. The same pest cut down the yield materially in this locality in 1920. The light production in the extreme upper limits of the yellow-pine type in 1918 might be accounted for by temperature conditions. Cutting is also believed to be a factor. The young trees left on cut-over areas respond to the effects of increased light and root space, but increased seed production apparently does not take place until about five years have elapsed. In a number of instances marked variations in seed production are noted in the absence of apparent differences of any kind.

European foresters have found that seed production follows fairly well-defined laws of periodicity. Records for yellow pine on the Coconino and Tusayan, although they are not long enough to provide a reliable basis, indicate that good seed crops occur rather generally every three to five years. During the intervening period one or two light crops and about the same number of complete failures may be expected. It is believed that the long period between good seed crops may be due to circumstances not connected with the fruiting habits of the tree. Repeated observations have shown that enormous numbers of cones die during the first season. Leiberg (*14*) attributes this to desiccation by the hot, dry winds which sweep this region during May and June. He also calls attention to inadequate fertili-

[5] Few cones fall until the second season following maturity.

zation due to the drying-up of the pollen, stating that in the cones which reach maturity not over 1 per cent of the ovules develop into perfect seeds. This estimate is undoubtedly much too low as an average figure, although it is known that fertilization is poor in some years. It is possible that late frosts have more to do with these conditions than dry winds. Whatever may be the cause, it is probable that many of the light seed crops would be good crops but for the arrested development of cones in the early stages. Much damage is done by weevils as the cones approach maturity, but serious infestations are usually of a local character.

CLIMATE.

The term "climate" embodies the primary physical factors concerned in plant growth, namely, heat, light, and moisture. It also determines in a large measure the physical and chemical composition of the soil. Several publications have described in considerable detail the forest climates of the Southwest (*24*), and particularly the region in and about the San Francisco Mountains (*13*, *14*, *17*, *19*). It is therefore necessary here merely to point out the most prominent features.

The western yellow pine type in the Southwest occurs at altitudes ranging from 6,500 to 9,000 feet. The mean temperature ranges from about 42° to 47° F. for the year, and from 59° to 65° F. for the growing season (June to September). Extremes fall as low as —25° F. and rise to 95° F., though temperatures below —20° F. and above 90° F. are unusual. The outstanding characteristics of the temperature in this region are a great daily range and the prevalence of frost during the growing season. The annual precipitation is about 23 inches, but it varies greatly in different places and in different years. At the Fort Valley Experiment Station the lowest and highest annual totals during the past 12 years are 15 and 32 inches. From the standpoint of reproduction, the dominating feature is the occurrence of protracted rainless periods, accompanied by high winds and high evaporation, during the months of May and June. In northern New Mexico this dry period is less pronounced than elsewhere in the two States. Undoubtedly this condition in a large measure accounts for the excellent reproduction which prevails generally on the Santa Fe and Carson National Forests.

MOISTURE THE DOMINANT FACTOR.

All of the studies which have been made point to moisture as the dominant physical factor in the reproduction of western yellow pine. Low temperature limits the upper altitudinal range of the species (*19*), but within its typical range this is not directly a limiting factor, excepting under special conditions. In shaded situations reduced

insolation retards the development of seedlings and may ultimately cause them to die. In a few instances early frosts have been known to injure young seedlings. High air temperature, within the limits encountered in the yellow-pine type, does not become a limiting factor excepting in association with deficient moisture. High temperature, wind, and low atmospheric humidity all tend to reduce the moisture supply by direct evaporation from the soil, and to increase the demands of the plant by inducing rapid transpiration. When these factors affect reproduction adversely it is almost invariably an indirect effect which makes itself felt in the moisture relation.

WINTERKILLING.

Seedlings or even grown trees often suffer from what is commonly known as winterkilling. The damage evidently occurs when the soil is frozen below the depth reached by the majority of the roots. The water in a frozen layer of soil can not be absorbed by the roots. If the weather is such as to favor active transpiration, the water loss may so far exceed the intake through the roots as to cause injury or death to the seedling. Usually only the leaves are killed, and new shoots appear with the approach of the growing season, but sometimes the stems also die. Damage of this character is usually associated with a deficiency of snow. Normally, however, the ground during the winter is covered with 2 or 3 feet of snow, which prevents deep freezing of the soil. This blanket checks transpiration of small seedlings which are buried, and thus renders them relatively immune from winterkilling, as compared with older trees which project above the snow.

FROST HEAVING.

Another common cause of injury results from low temperature accompanied by high soil moisture. This is what is known as frost heaving, or ground heaving. As the surface soil layers expand and lift in freezing, they pull out or break off the roots of young plants. The greatest losses occur on wet, poorly drained sites. More damage seems to occur when the ground is bare than when it is continually under snow. For this reason the damage is worst in late fall and early spring and in open winters. Perennial vegetation is beneficial, both as a soil cover and as a soil binder. Haasis (*6*) has found that substantially lower losses occur where the ground is covered with grass or loose branches than where it is bare. Shallow-rooted plants, as well as pine seedlings, however, are sometimes thrown completely out of the ground. The winter of 1919–20 was particularly trying, because a large proportion of the precipitation came in the form of rain instead of snow. On spots which were bare of snow in February the losses among first-year seedlings ran as high as 50 per cent

and averaged around 25 per cent. For all sites in the vicinity of the Fort Valley Experiment Station in the winter of 1919–20 the average losses from heaving were 17 per cent for first-year and 8 per cent for older seedlings. These figures represent 55 and 86 per cent, respectively, of the total losses from all causes. Although frost heaving is responsible for much damage, particularly to first-year seedlings, it is not of sufficient importance to be classed as a limiting factor.

GERMINATION AND SURVIVAL IN RELATION TO RAINFALL.

Records at the Fort Valley Experiment Station show that germination and survival of pine seedlings are closely associated with moisture. In the absence of adequate records of soil moisture, evaporation or precipitation, or preferably both, may be used as indices. The best single index is precipitation. It is believed to be entirely adequate in this region for studies involving long periods of time and not requiring minute distinctions. Moreover, in the Southwest, rainfall furnishes a fairly good index to evaporation. In periods of abundant rainfall evaporation is always low, because of high atmospheric humidity, more or less cloudy skies, and low wind movement; in periods of light or no rainfall evaporation is high, because of low atmospheric humidity, prevailingly clear skies, and high wind movement. These relationships do not always hold for short intervals, but they do hold when periods of 10 days or more are considered.

Contrary to the usual impression, germination is not a serious problem in the reproduction of western yellow pine in this region. Germination takes place in July and August, because usually this is the only period when both moisture and temperature conditions are favorable. In April and the first half of May the soil is often moist, but the temperature is too low. From the middle of May to the end of June temperature requirements are satisfied, but the surface soil is too dry. Usually this period is practically rainless. During the past 11 years May or June germination has occurred in the San Francisco Mountains region only once, in 1919, when for two weeks in the latter part of May rain fell almost daily. Normally the summer rains begin between July 1 and July 15, and continue six or eight weeks. During this period showers may occur almost daily during continuous intervals of three weeks or more. Such conditions are ideal for germination. The critical tests come in dry periods during the first and second seasons after germination.

Figure 2 gives a record of rainfall plotted by 10-day periods from 1909 to 1920. Tables and figures in the chapters "Cutting" and "Brush disposal" show the fluctuations of soil moisture during the growing season in 1909, 1912, 1919, and 1920. Both rainfall and

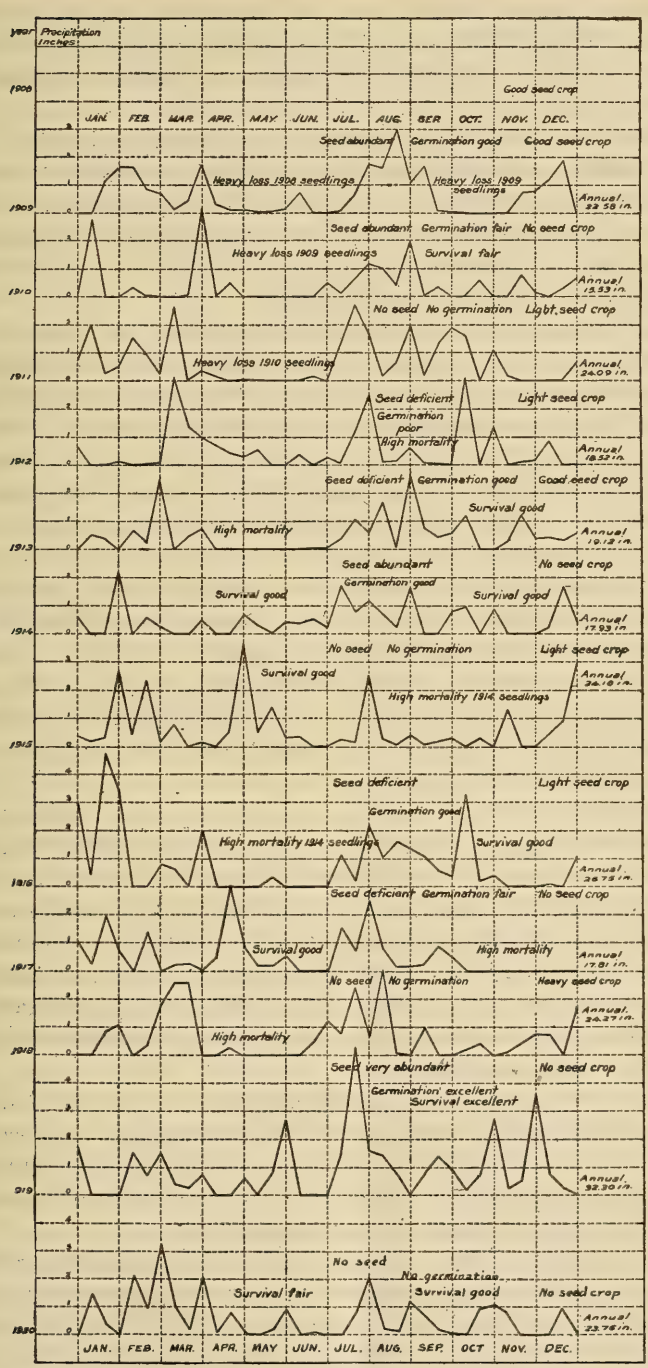


FIG. 2.—Reproduction as related to seed and rainfall.

soil-moisture graphs show a marked depression in May and June, a peak in July and August, and a secondary depression of varying intensity in the fall months. Moisture is usually abundant from December 1 to April 1.

Successes and failures in reproduction during the past 11 years may be readily accounted for by correlating rainfall and seed supply, as shown in Figure 2. The requisites for success are a good seed crop, followed by abundant rain in July and August of the next year, and an absence of severe droughts during at least one and preferably two years after germination.

A study of age classes in the vicinity of the Fort Valley Experiment Station reveals a conspicuous absence of seedlings originating between 1908 and 1914. An analysis of Figure 2 explains this. A good seed crop was borne in the fall of 1908, and it germinated abundantly during the rainy period of July and August, 1909. But no rain fell during the 60-day interval from about September 10 to November 15. A drought of equal duration occurred in May and June of the following year. No exact counts are available, but it is known that seedlings were abundant in August, 1909, and that few remained a year later. Another good seed crop occurred in 1909. Germination was fairly good in July and August, 1910. The September-October drought was not severe, but from April 1 to July 1, 1911, the rainfall was limited to a few light showers totaling less than one-half inch. It is not surprising that few seedlings remain from the 1908 and 1909 seed crops.

The protracted summer and fall rains of 1911 gave rise to no seedlings, because no seed matured the preceding year. Here we have an excellent illustration of the failure of reproduction with an abundance of moisture, because seed was lacking. Germination and survival would have been excellent in 1911. With the absence of a severe dry period in May and June, 1912, a large percentage of seedlings would have survived. The rainfall of August and September, though too irregular for germination, was sufficient for seedlings a year or more of age.

The light seed crop of 1911 germinated poorly, because of deficient rainfall in July and August, 1912. On plots which had been artificially sown, a few seedlings came up in July, but died during the drought of August and September. All that survived succumbed during the 90-day drought of April–July, 1913.

Had the seed production of 1912 been better, excellent reproduction would probably have resulted, because the abundant and well-distributed rainfall during the summer and fall of 1913, and throughout 1914 and the first half of 1915, favored a high survival.

Another good seed crop matured in the fall of 1913. Abundant moisture throughout 1914 resulted in good germination and survival.

The foresummer of 1915 did not bring the usual prolonged drought, but the summer rains were light. Records for sample plots 3A and 3B (Table 3) show a heavy loss of 1914 seedlings during the fall of 1915, and again in the spring of 1916, when no rain fell from April 1 to July 7, save for a shower of 0.35 inch in May. Nevertheless, the seedlings which originated in 1914 were sufficient in number to make a real start toward restocking sample plots 3A and 3B. This survival is attributed to the absence of severe droughts in the fall of 1914 and the spring of 1915. Had the summer rains of 1915 been up to the usual standard, and if the April–June drought of 1916 had been less severe, it is reasonable to believe that a much higher survival would have resulted. As it was, excellent reproduction took place on local areas in the vicinity of Fort Valley and on extensive areas in other localities. The poorer showing on sample plots 3A and 3B, as compared with certain other areas, is attributed partly to the heavy soil on these plots and partly to the fact that the seedlings were forced to compete with a dense growth of grass. Results in this region, as a whole, form the basis for the conclusion that if a good seed crop is followed by one year of abundant and properly distributed rainfall, good reproduction will take place on the more favorable sites, but that on the more adverse sites two or more consecutive years of favorable moisture conditions are required.

No seedlings originated in 1915, because of a total absence of seed. The rainfall graph from August 1 to October 31 points clearly to the fate which would have awaited any seed which might have been borne in 1914.

The light seed crop of 1915 gave rise to appreciable numbers of seedlings. This result is attributed to the favorable summer and fall of 1916 and the absence of a severe drought during May and June of the following year. Beginning in the latter part of September, 1917, and extending to the middle of January, 1918, we had the longest continuous rainless period of 12 years. Notwithstanding heavy losses of both first and second year seedlings, a few survived. Seedlings over 2 years old resisted the drought surprisingly well. No doubt the mortality in all age classes would have been heavier but for the fact that the soil did not become very dry until after the close of the growing season.

In the fall of 1918 a tremendous seed crop occurred generally over the entire Colorado Plateau. It was particularly heavy in the vicinity of the Fort Valley Experiment Station. Rain was abundant and well distributed during practically the entire growing season of 1919. For the first time on record germination took place in May and early June. Most of these seedlings survived a light drought in the latter part of June, and they were supplemented by myriads during the summer rainy period, which began promptly

on July 1. So favorable were moisture conditions that pine seeds germinated wherever they were even partially covered. It was a common sight to find vigorous young seedlings emerging from the cracks and decayed places in fallen tree trunks. Not only were the seedlings at the end of the season more abundant than usual, but they were larger on account of the unusually long growing season and the uninterrupted growth made possible by a continuous supply of moisture. In the spring of 1917, first-year seedlings originating in 1916 had an average root length of 6.4 inches and an extreme length of 9.5 inches. Seedlings dug in the fall of 1919 had an average root length of 10 inches and an extreme length of 17 inches. The dry period in the foresummer of 1920 was generally considered severe, but a comparison with previous years shows that it was less protracted than in 1909, 1911, 1913, 1916, and 1918. Certain sites suffered a high mortality, but, as a rule, survival was ample. Although the summer rains were light, the records disclose no great loss after the drought of the foresummer was broken. The open winter of 1919–20 favored ground heaving because of the excess of moisture in the form of rain, accompanied by alternate freezing and thawing. Certain sites show a loss of over 50 per cent from this cause, but the average was only about 20 per cent, and the consequences were on the whole not serious. The winter of 1920–21 was not only open but dry, in consequence of a deficiency of both snow and rain. Such conditions favor winterkilling. Nevertheless the total winter losses averaged only about 20 per cent. All things considered, the period from 1918 to 1921 has been the most favorable one from the standpoint of reproduction that has been experienced since the initiation of records at the Fort Valley Experiment Station, and probably the most favorable in 25 years. Although success is still not definitely assured, the present outlook warrants the expectation of good reproduction on the bulk of the area, which is adequately protected against fire and grazing.

A survey of the graphs in Figure 2 shows that since 1908 there have been three periods during which the distribution and amount of rainfall have been such as to permit the establishment of pine seedlings in appreciable numbers. They are 1911–12, 1913–1915, and 1918–1920. The minimum interval here considered is 1½ years, beginning with normal rains in July and August and continuing without a severe drought during the remainder of the first season and all of the second season. In two instances, however, such conditions prevailed during a 2½-year interval.

During the period covered by the rainfall graphs, good seed crops occurred in 1908, 1909, 1913, and 1918. Since the seed does not germinate until the year after it is borne, the right coincidence be-

tween seed production and rainfall occurs only when a seed year immediately precedes a period of ample moisture. The 1908 and 1909 seed crops both failed to give results because they were not followed by sufficiently long periods of immunity from severe drought. Similarly, the favorable moisture periods of 1911–12 and 1918–19[6] were unavailing because they were not preceded by good seed crops. The seed crop of 1913 was effective because no really serious drought occurred until the foresummer of 1916. It would have been still more effective if there had been more precipitation during the summer and fall of 1915 or if the seed had been available a year earlier, thus taking advantage of the entire rainy period, which extended from July, 1913, to August, 1915. The grand climax came with the heavy seed crop of 1918 and the extraordinary precipitation of 1919, followed by reasonably favorable moisture conditions in 1920. This period promises to give the best reproduction experienced on the Coconino in 40 years. Success would have been still more certain, however, if the seed which matured in 1918 had been available a year earlier, thus profiting by the two consecutive wet summers of 1918 and 1919. During the entire period of 12 years, two good seedling crops of general distribution have originated on the Coconino and Tusayan Forests, and only one of these, that of 1919, was adequate to give full stocking over extensive areas.

SOIL.

The general characteristices of soils which influence plant growth and by which they can be most logically grouped are determined by climate. The effect of the climatic conditions prevailing over the western yellow-pine belt of Arizona and New Mexico has been to produce soils, in general, low in their content of humus or completely decomposed organic matter; comparatively high in content of mineral elements of plant food; high in content of lime carbonate at the lower altitudes or localities of lowest precipitation and generally alkaline (neutral at the higher altitudes) in reaction; and generally coarse, since rock decomposition has not kept pace with rock disintegration. These general characteristics are modified locally by the nature of the rock from which the soil is derived, by the slope of the land, and by the age of the soil. The rock underlying the yellow-pine belt is, over the greater part of the area, of volcanic origin, mainly basalt, but limestone, sandstones, conglomerate clays, and old granitic rocks are also present. Physiographically, this is a region of mountains and high plateaus. The plateaus are deeply incised by streams, resulting in regions of comparatively level or rolling table-land and rough broken topography adjacent to the plateau rims and in the canyons. The geology and topography of the region are varied, and owing to the influence of these factors there are a number of soil types and locally important differences in mechanical composition, structure, and percentages of chemical compounds in the soil. (J. O. Veatch.[7])

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[6] A heavy seed crop matured in 1918 and germinated in 1919, but no germination occurred during the prolonged rainy summer of 1918, because no seed was produced in 1917.

[7] A full discussion of the geology of the San Francisco Mountains region is given by Robinson (*21*). See also soil description in the following pages.

RELATION BETWEEN REPRODUCTION AND CHARACTER OF SOIL.

Observations throughout the yellow-pine type in Arizona and New Mexico indicate that yellow pine reproduction is uniformly better on the coarser, sandy, gravelly, or stony soils than on the finer soils, regardless of geologic origin. Since the finer materials are deposited in the valleys and flats, reproduction is usually poorer in such situations than on the slopes. On table-lands, where the soil is mainly residual, the best reproduction is always associated with the presence of stones or gravel. Often the soils on which seedlings are most numerous are too shallow or too stony to support a good stand of timber, whereas the deepest and most fertile soils, which produce the heaviest stands once they are well stocked, are often stocked below their capacity because they are unfavorable to the establishment of seedlings.

SOIL SURVEYS.

The above observations are confirmed by detailed studies of a number of areas on which the soil types were mapped by J. O.

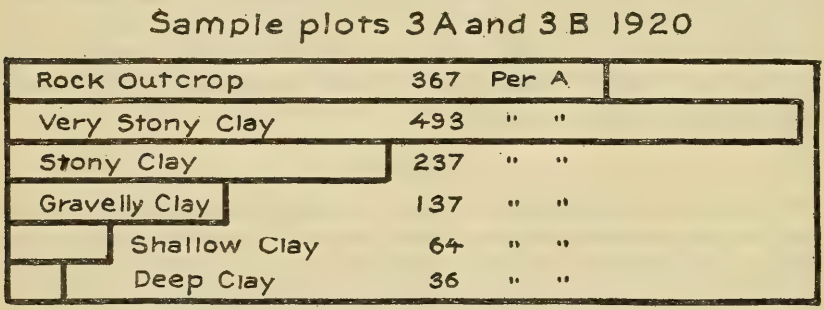


FIG. 3.—Number of seedlings per acre on various soils.

Veatch, of the U. S. Bureau of Soils. Special attention was given to sample plots 3A and 3B previously mentioned, because these plots are typical of extensive areas which are restocking unsatisfactorily. Table 10 and Figure 3 give the results of seedling counts in the most prevalent types of soil on these two plots. All seedlings over 2 years old (omitting the 1919 crop) were counted by 1-chain squares (Fig. 1). In order to avoid transition zones between types, and to simplify computation of area, counts were made, with a few exceptions, only on squares which fall entirely within a single soil type as indicated by the map.

Description of soils.—The following soil descriptions were prepared by J. O. Veatch, of the Bureau of Soils, and based upon field examinations made by him in 1919.

PLOT 3A.

The soils belong in the upper part of the Coloradan soil zone, to the Tusayan types and geologically to the basalt group. The mineral base of the various soil

divisions is from the same source and the divisions are essentially the same in chemical character. All of the soil is essentially the same in the physical nature of the profile or succession of separate horizons. The divisions shown on the map are for the most part soil *phases* rather than *types* since they are based merely upon small differences in thickness of the soil layer, and in amount of stone and gravel which may be either on the surface or incorporated in the soil. The soil of the plot as a whole is fairly representative of what is probably the most extensive soil site in the yellow pine forest in the Tusayan and Coconino National Forests.

Soil No. 24.

DESCRIPTION OF SOIL PROFILE.

Surface soil dark reddish clay loam or clay, underlain by a somewhat stiffer and more compact red clay at 4 to 6 inches; this extends to depth of 18 inches to 3 feet, becoming a lighter shade of color and more friable at base because of the increased stone and gravel content. The soil layer rests upon solid bedrock of basalt or upon reddish coarse fragmental blocks of somewhat scoriaceous basaltic lava. Generally a small amount of fragments of gravel size and smaller per cent of stones are scattered over the surface and incorporated in the soil. The humus content is low. The soil is mainly residual.

RELATION TO YELLOW PINE AND VEGETATIVE CHARACTER.

Soil layer thin, clay difficultly permeable and root development circumscribed. Where plant mold from grasses is absent, the surface clay tends to become hard and compact. Conditions for germination and survival not as favorable as on soils 6 and 12. Fairly dense cover of *Festuca arizonica* and *Muhlenbergia montana.*

Soil No. 6.

SOIL DESCRIPTION.

Surface soil moderately friable, reddish-brown clay loam underlain at about 6 inches by stiff red clay. Similar to soil 24, but on the average less in thickness, while stones are scattered more freely over the surface, constituting probably 50 to 75 per cent of the total surface area. More humus and a more loamy surface soil than that of 24. The bedrock is generally impenetrable for tree roots.

RELATION TO YELLOW PINE GROWTH.

Soil is favorable for germination and survival. Root development circumscribed, and increment would not be expected to be as high as on soils 9 and 20.

Soil No. 12.

SOIL DESCRIPTION.

The areas numbered 12, characterized by rock outcrop and detached boulders projecting from a few inches to 2 or 3 feet above the surface or soil line. Seventy-five to 95 per cent of surface area occupied by rock. Greater accumulation of litter and humus at surface than on other types producing a more friable or loamy soil. Soil covering very thin, consisting for the most part merely of a few inches of humus soil resting upon the rock, but in places a stony red clay subsoil is present in the deeper pockets.

RELATION TO YELLOW-PINE GROWTH.

Soil favorable for germination and high percentage of survival. On account of the thinness of the soil layer a comparatively low increment would be expected. Roots can not develop downward as freely as on other types on account of rock obstruction.

Less density of grass cover than on other types, greater proportion of *Muhlenbergia montana* and *Andropogon scoparius*. Shrub *Ceanothus* more common than on other divisions.

Soil No. 9.

SOIL DESCRIPTION.

Brownish or reddish brown moderately friable loam to clay loam to 4 to 6 inches, becoming heavier in texture and more reddish with depth, thus grading into very stiff, compact red clay. Bed rock is encountered at an average depth of not more than 3 to 4 feet. This soil is found at bases of slopes and in the drainage swales. The surface soil consists largely of colluvial wash for at least 6 to 10 inches. Rather high percentage of rock fragments, mostly of gravel size, scattered over the surface and incorporated in the soil. Surface contains a little higher percentage of humus than divisions 24, 28, and 20. Does not bake or crust and is a little better aerated to a greater depth than in the divisions just mentioned. Underlying clay difficultly penetrable; highly retentive, once thoroughly wetted.

RELATION TO YELLOW-PINE GROWTH.

Percentage of seedling survival would be expected to be fair, but probably somewhat less than the stonier soils. Increment should be nearly as good or equal to that on soil 20.

Fairly dense cover of the common grasses *Festuca arizonica*, *Muhlenbergia montana*, and *Blepharoneuron tricholepis*.

Soil No. 20.

DESCRIPTION OF SOIL.

Reddish-brown or chocolate-red compact clay loam grading into compact reddish clay which extends to 20 to 48 inches and thence rests either upon a thin layer of stiff residual clay or upon the bedrock of basalt. The soil consists mainly of the finer alluvial and pluvial wash deposited in the shallow swale which traverses the plot from east to west. There may be a few scattered stones and gravel on the surface or in the soil, but on the whole it is freer from coarse rock fragments than other divisions. It is moderately impervious, but highly retentive. Surface denuded of the natural veneer of grass mold bakes and crusts slightly.

RELATION TO YELLOW-PINE GROWTH.

Natural reproduction may not be as abundant as on the more stony and gravelly soils, but growth once started should be more rapid on the assumption that there is greater fertility and total available moisture in the same volume of soil.

Festuca arizonica-Muhlenbergia montana association forming a denser cover than on other types.

Soil No. 28.

DESCRIPTION OF SOIL.

Reddish-clay loam to clay surface soil 6 to 15 inches, consisting mainly of colluvial wash resting either upon the bedrock or upon a very thin layer of stiff, red, residual clay. Soil texture and structure very similar to soil 20, but soil layer is less in thickness. Smaller percentage of gravel, surface slightly more compact, and not as well aerated as soil 9.

RELATION TO YELLOW-PINE GROWTH.

Percentage of germination and survival may not be as high as on more stony and gravelly soils, but increment may be fair. The downward development of roots is limited to shallow depths.

PLOT 3B.

The soils of this plot belong in the upper part of the Coloradan Soil Zone, to the Tusayan types, and in geologic classification to the basalt group. The mineral bases of the soil divisions of the plots are from the same rock source and probably essentially the same in chemical character and also the same in physical character of the soil profile as in Plot 3A. There is a slightly larger proportional area of extremely stony soils, 12 and 6, and a somewhat smaller area of nearly stone-free soils.

TABLE 10.—*Seedling soil survey.*

And=*Andropogon scoparius*, Ann=Annuals, Bl=*Blepharoneuron tricholepis*, C=*Ceanothus fendleri*, Er=*Erigeron divergens*, F=*Festuca arizonica*, Lot=*Lotus wrightii*, Lup=*Lupinus hillii*, M=*Muhlenbergia montana*, Pan=*Panicum* sp., Sit=*Sitanion molle* and *S. brevifolium*, Vic=*Vicia americana*.

1. SAMPLE PLOT 3A (AUGUST–SEPTEMBER, 1920).

Plot.[1]	Vegetation in order of abundance.	Number of seedlings.[2]
	Soil No. 12, rock outcrop:	
H 8	And, C, M, Lot	55
H 9	M, And, Lot, C, F	24
H 10	And, Lot, C, Pan, M	17
0.28 acre.	Total	96
	Per acre	343
	Soil No. 24, stony clay:	
K 8	M, Lot, F	13
L 1	M, F	5
L 8	Lot, M, F	29
L 9	F, M, Vic	21
0.4 acre	Total	68
	Per acre	170
	Soil No. 9, gravelly clay:	
A 5	F, M, Lup	10
B 2	M, Bl, F, Vic, Lup	11
C 5	F, Sit, Lup, Ann	0
H 6	M, F, Bl	4
J 4	M, Bl, Vic, F	10
	Soil No. 9, gravelly clay—Con.	
K 10	M, Bl, Vic, F	52
K 4	F, M, Bl, Lup	9
0.7 acre	Total	96
	Per acre	137
	Soil No. 20, fine clay:	
D 1	F, Lup, M, Vic	0
E 1	F, M (Seedlings mainly in brush or old road.)	6
E 5	F, Lup, Vic (Seedlings mainly in brush or old road.)	5
0.3 acre	Total	11
	Per acre	37
	Soil No. 28, shallow clay:	
C 3	M, F, Vic, sparse	17
F 6	F, Lup, Vic	1
H 4	F, M, Bl, Sit	12
H 5	F (nearly pure), M, Lup	0
I 5	F (nearly pure), M, Vic	2
0.5 acre	Total	32
	Per acre	64

[1] All plots contain 0.1 acre, excepting H 8, which is 0.08 acre.
[2] Only seedlings over 2 years old counted. Nearly all are 4 years or over.

TABLE 10.—*Seedling soil survey*—Continued.

2. SAMPLE PLOT 3B (SEPTEMBER, 1920).

Plot.[1]	Vegetation in order of abundance.	Number of seedlings.[2]
	Soil No. 12, rock outcrop:	
H 5	Lot, M, C, F, And	49
H 6	Lot, M, C, Vic, Lup	31
0.2 acre		
	Total	80
	Per acre	400
	Soil No. 6, very stony clay:	
D 6	M, F, Lot	26
H 3	F, M, Lot, sparse	62
I 3	M, Lot, Sit	18
I 7	M, Vic, Sit	54
J 6	Sit, M, F, Vic, Lot	47
J 7	Vic, M, Lot	81
L 1	Lot, M	78
L 2	M, Vic, Lot	68
J 4	M, Sit, Vic	10
0.9 acre		
	Total	444
	Per acre	493
	Soil No. 24, stony clay:	
D 4	F, Vic, M	22
E 4	F, Sit, Vic, Ann	29
	Soil No. 24, stony clay—Cont'd.	
E 10	M, Lot, Vic, Sit, F, Er	37
F 3	F, M, Vic	8
G 9	Vic, Lot, M, F	11
J 9	F, M, Vic, Lup	13
K 9	M, Vic, Sit, Lot, F	53
L 7	F, M, Lot, Vic, Sit	45
L 8	M, Lot, Vic, F, Sit	21
L 9	M, F, Lot, Vic	14
L 10	Lot, M, Vic	34
1.1 acre		
	Total	287
	Per acre	261
	Soil No. 20, fine clay:	
A 3	F, Vic, Lup, Sit	0
A 10	F, Vic	6
C 2	F (almost pure)	5
D 2	F (almost pure), Vic, Lup	8
E 1	F, M, Vic	4
E 2	F (very rank), Ann, Vic	0
F 1	F, M, Lot	2
0.7 acre		
	Total	25
	Per acre	36

SUMMARY OF SAMPLE PLOTS 3A AND 3B.

Soil.	Acres.	Number of seedlings.	
		Total.	Per acre.
No. 12, rock outcrop	0.48	176	367
No. 6, very stony clay	.9	444	493
No. 24, stony clay	1.5	355	237
No. 9, gravelly clay	.7	96	137
No. 20, fine clay (deep)	1.0	36	36
No. 28, shallow clay	.5	32	64

Reproduction in various types of soil.—It should be noted that the groups of plots in Table 10 are arranged in the order of the relative amounts of stone or gravel contained. A possible exception may occur in the case of Nos. 20 and 28, the latter of which is usually somewhat the more gravelly. It should also be borne in mind that all of these soils are distinctly clayey. The varying degrees of loaminess referred to in the descriptions apply only to a surface layer varying from 2 to 12 inches deep, or in rare cases slightly deeper. The seedling counts leave no doubt as to the favorable influence of rock or gravel. Since practically all of the seedlings were over 3 years old and the majority over 5 years old at the time of the examination, the data should furnish a reliable index as to ultimate survival on the various soils.

There also seems to be a definite relation between soil, reproduction, and herbaceous vegetation. Where *Festuca arizonica* is dis-

tinctly dominant, pine reproduction is usually deficient. The soil in such situations is usually a deep, stone-free clay. *Muhlenbergia montana* predominates on the stony or gravelly soils, excepting in the most rocky situations, where *Andropogon scoparius* is usually more abundant. In either case reproduction is usually good. *Vicia americana* and *Lotus wrightii* are common associates of *Muhlenbergia montana* and indicate a good site for pine reproduction. *Lupinus hillii* and several other broad-leaved plants occur mainly where the original grass cover has been disturbed. This subject is discussed in greater detail under "Herbaceous vegetation."

Mechanical analyses.—Mechanical analyses have, as a rule, failed to bring out consistent relationships between success of reproduction and the physical composition of soils. In the light of recent findings, this is attributed to the fact that in the analyses which have been made, following the conventional method, all material above 2 millimeters in diameter was disregarded. It is now known that in the clay soils of this region the particles above 2 millimeters in diameter may be of far greater importance than the fine gravel or sand, which are often present only in negligible quantities.

Chemical analyses.—Chemical analyses have likewise failed to throw much light on the problem. This does not mean that chemical composition is unimportant, but rather that within the areas now occupied by western yellow pine the chemical variations apparently are not sufficient to affect reproduction appreciably. The only suggestion of unfavorable conditions due to chemical composition of the soil is in the lower portion of the yellow pine type, where Veatch (*25*) has found indications that the occurrence of yellow pine may be limited by the presence of excessive quantities of calcium carbonate. If such a condition does exist, it is probably a consequence of deficient precipitation, so that the calcium carbonate fails to leach out as it does in the higher altitudes, where precipitation is more abundant.

HOW MECHANICAL COMPOSITION OF SOIL AFFECTS GROWTH OF SEEDLINGS.

Although much remains to be done on the soil problem, it is believed that substantial progress has been made in establishing a relationship between reproduction and gross physical characteristics of the soil, as determined by the presence of varying amounts of sand, gravel, and stones. This information is especially valuable to the forester, because it can be readily understood and applied without special training in soil physics. Thus far, however, we have merely established the fact that reproduction is best on the coarse-grained or stony soils. Although the fact itself is important, it can not be employed to the best advantage without an understanding of the

underlying causes. Further investigations are required for a complete explanation, but the following observations will serve to call attention to some of the factors involved.

MOISTURE.

The entire soil problem in the Southwest revolves about the question of moisture. We have abundant evidence that practically all of the soils in the yellow pine type of this region will grow yellow pine from the seedling stage to maturity if the water supply is sufficient. But a limited supply of moisture is more effective in some soils than in others. This is especially important during the seedling stage, because the seedling is not equipped with an adequate root system to meet its demands when the supply of available moisture in the soil is low. It is a well-known fact in agriculture that sandy soils, though having a lower water-holding capacity and lower retentive qualities than clay soils, are able to deliver moisture to plant roots in drought periods when none can be secured from the clay soils. It is also a well-known fact that pines thrive better in sandy than in clay soils. The reasons for this are that sandy soils permit deeper root penetration, absorb rainfall more readily, are better aerated, and, as stated above, furnish a greater proportion of the moisture to the plant roots in droughts than clay soils.

But the sandy soils are not really concerned in the reproduction problem of the Southwest, because where the soil is sandy, reproduction of western yellow pine is not, as a rule, difficult to secure. The reproduction problem is limited mainly to the basaltic clay soils which are prevalent on the Coconino and Tusayan National Forests. On the southern portion of the Coconino, and on the Sitgreaves and the Apache Forests, soils apparently similar to the basaltic soils above mentioned bear excellent stands of reproduction, but close examination will show that they are more sandy or gravelly and, as a rule, have a deeper loamy surface layer than the Coconino and Tusayan soils, which bear poor reproduction. The important fact is that, even though the soil proper may be classed as a clay, reproduction will succeed if liberal quantities of stones are mixed in the soil mass. There are a number of obvious advantages due to this admixture of stones. Where they occur on the surface in considerable quantities they check run-off. They also act as a mulch against evaporation. Water percolates deeply in the soil by following the surfaces of partially embedded rocks. Haasis (*6*) has pointed out that there is often a distinct line of cleavage between the surface soil and the rock, caused by frost. He also calls attention to the fact that the volcanic rocks, because of their porous structure, absorb considerable quantities of water, which may become available after the surrounding soil has become relatively dry. He has found that the roots of pine seedlings often follow the

F—89856

FIG. 1.

F—43835A

FIG. 2.

FIGS. 1 AND 2.—A CLAY FLAT ON WHICH REPRODUCTION HAS MADE ALMOST IMPERCEPTIBLE PROGRESS IN 10 YEARS, DESPITE ADEQUATE SEED TREES AND COMPLETE PROTECTION.

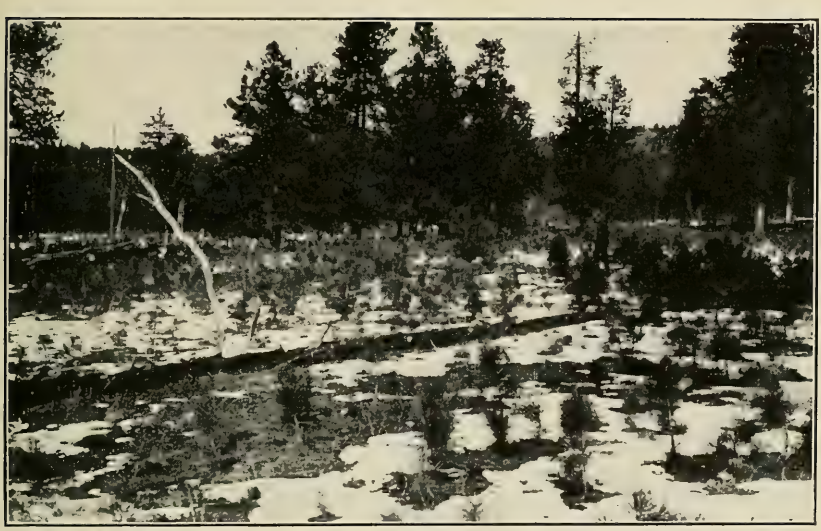
The causes are a stone-free clay soil and a dense growth of bunchgrass. Upper photograph taken in 1909, lower in 1919.

F—43866A

FIG. 1.—GOOD REPRODUCTION OF SEVERAL AGE-CLASSES ON STONY CLAY SOIL. THE GRASS HERE IS MAINLY MUHLENBERGIA MONTANA. THIS ASSOCIATION OF SOIL AND GRASS USUALLY INDICATES A FAVORABLE SITE FOR REPRODUCTION OF WESTERN YELLOW PINE.

F—160232

FIG. 2.—GOOD REPRODUCTION ON ROCKY SLOPE; NONE ON CLAY FLAT IN FOREGROUND. THIS RELATIONSHIP BETWEEN THE TWO SITES IS CHARACTERISTIC.



F—150924

FIG. 1.—EXCELLENT REPRODUCTION ON GRAVELLY LOAM SOIL, GRAZED BY CATTLE AND HORSES, BUT NOT BY SHEEP.

F—49198A

FIG. 2.—WESTERN YELLOW PINE, 4 YEARS OLD, TRANSPLANTED IN GREENHOUSE AT THE AGE OF 2 YEARS. THE CAN ON THE RIGHT WAS FILLED WITH A MIXTURE OF ONE-HALF LOAM, TAKEN FROM THE UPPER FOOT IN THE YELLOW PINE FOREST, AND ONE-HALF SAND.

The can on the left was filled with clay taken from underneath the loam in the first can.

rock surfaces and even penetrate the pores. Veatch (*25*) cites an instance in 1919, when after a prolonged rainy period, the stony clay soils near the Fort Valley Experiment Station were penetrated by moisture to a depth of 3 feet or more, whereas a stone-free clay was penetrated only from 12 to 13 inches. This condition, however, applies only during the period of summer showers. The fine clays, as well as other soils, are usually saturated to a great depth by winter precipitation.

Germination also is closely related to the texture of the soil. Fine clay soils usually form a smooth, compact surface, especially if tramped by grazing animals. Seeds are not readily covered, and if they are covered the clay forms a hard crust which the tender seedling may not be able to break through. These adverse conditions are relieved by gravel and stones mixed in the surface layer or loose on the surface. This subject is treated more fully under "Herbaceous vegetation."

ROOT DEVELOPMENT.

The survival of young seedlings during critical droughts is determined by the amount of available moisture within the soil mass occupied by their roots. Obviously a seedling whose roots are not in contact with a fairly constant source of moisture has a poor chance for survival. Not only depth of roots but also lateral extension is important, because, other things being equal, the amount of moisture available is proportional to the volume of soil drawn upon. In view of these facts, a study of the form and depth of the root systems of pine seedlings in various soils may throw considerable light upon the reproduction problem.

Haasis in 1919 and 1920 excavated the root systems of some 200 western yellow pine seedlings, ranging from 1 to 5 years of age. He found the shallowest penetration in the gravelly and loamy soils, the deepest in fine clay, and intermediate penetration in stony clay. Lateral development was least in the fine clay, greatest in gravelly soils or cinders, and intermediate in stony clay. He formulated the general rule that the more compact the soil the deeper and less branching the root, and the looser the soil the shallower and more branching the root. This is contrary to the observation that roots of mature trees do not penetrate deeply in clay soils because of the compact structure. In the case of trees, however, we are dealing with greater depths, down to 3 or 4 feet. It is possible that the failure of roots to penetrate below this depth may be due to other causes such as insufficient aeration. Moreover, bedrock or hardpans are usually encountered at less than 4 feet. In the light of Haasis's investigations it appears that the roots must penetrate deeply in clay soils in order to secure moisture, and that the seedlings which do

not succeed in sending their roots into the lower strata during the first season usually die. This may also explain why yellow pine does not occur on clay soils in this region where the annual precipitation is below about 16 inches, and where, in consequence, the moisture does not penetrate deeply. The average depth reached by the roots of first-year seedlings at Fort Valley in 1919[8] was 12.4 inches in fine clay, 8.7 inches in stony clay, and 7.1 inches in gravelly soils. In fine clay the laterals are mostly near the lower end of the root, in gravel and cinders near the surface, and in stony clay near the middle third. It is evident that, excepting in the fine-clay soils, first-year seedlings secure most of their moisture from the upper 6 inches of soil.

Presumably the roots of a plant develop more or less in response to its needs, and therefore the form of the root is an index to the conditions prevailing in the soil. If this assumption is correct, the absence of laterals in the upper strata of the fine clay indicates a deficiency of available moisture in these strata. It also follows that the main root will penetrate deeply in order to follow the rapidly subsiding moisture with the approach of a dry period, and that the laterals will develop at a considerable depth where the moisture supply is fairly constant. The above conception corresponds with the known fact that the clay soils dry out rapidly at the surface, but are very retentive of moisture at the lower depths. Following the same course of reasoning, it is inferred that roots penetrate less deeply in the stony clay and gravelly soils, because they find sufficient moisture in the upper layers, which also offer advantages in aeration, temperature, and supply of organic matter.

HERBACEOUS VEGETATION.

Even the densest forests of yellow pine in the Southwest support a large amount of herbaceous vegetation of high light requirement. Rarely does the crown canopy of the trees cover more than 30 per cent of the total ground area, and usually not over 25 per cent. The ground directly under and for 20 to 30 feet north of the larger groups of trees is usually almost bare of herbaceous growth, although sometimes a luxuriant cover of lupine, vetch, and other shade-enduring plants may be found in such situations. On the Coconino and Tusayan National Forests the openings between the trees, which in virgin stands are often from 100 to 150 feet in diameter, are usually occupied by grasses. Cutting enlarges the openings and thus favors the development and extension of herbaceous cover. It is the forester's aim, however, to stock with trees both the original large openings and those made by cutting.

[8] These figures are higher than for average years.

PROTECTION VS. COMPETITION.

That herbaceous vegetation must exercise an important influence upon forest reproduction is self-evident. On the one hand, there is competition for moisture and light, in which young seedings may be assumed to be handicapped in the struggle with their older neighbors, particularly the grasses. On the other hand, this vegetation affords protection against excessive insolation, wind, frost, and other adverse physical conditions. What the net results of these opposing influences might be has for several years been a matter of conjecture. Studies during the past two years have furnished considerable new data on this subject.

Sample plots 3A and 3B, fenced against all grazing animals for over 10 years, show that competition with grasses is less disastrous to yellow-pine seedlings than might be expected. Although the grass has no doubt retarded the rate of progress, reproduction is proceeding steadily, as shown by Table 2. On portions of these plots, the bunch grasses, *Festuca arizonica*, *Muhlenbergia montana*, and *Blepharoneuron tricholepsis*, grow 2 or 3 feet high and probably have attained the maximum density which the soil and climatic conditions will permit. In the densest grass areas reproduction appears to be strongly handicapped, but even here a few seedlings have succeeded in establishing themselves. In moderately dense grass, where about half the ground surface is covered, progress has been very encouraging. Although some seedlings are unquestionably shaded out, the consequences of shade are not on the whole really serious. Root competition is the vital factor. The critical time during the first season is in September, after the summer rains have ceased and the grasses still make heavy demands upon moisture. If the summer rains are light and of short duration, the seedling loss is likely to be heavy. If, as in 1919, the soil is well supplied with moisture through the growing season and well into the fall, competition for moisture is not severe. Early frosts that stop the activity of herbaceous plants also retard the depletion of soil moisture. In the summer of 1919 great numbers of seedlings sprang up in the densest herbaceous cover. Some were killed or injured by shade, particularly under leafy plants such as lupine and vetch, but there was no evidence of injury by drought, and on the whole the survival was good.

GERMINATION AND EARLY SURVIVAL FAVORED BY HERBACEOUS COVER.

Denudation by cultivation.—In 1914, thirty-four 5 by 10 foot plots on sample plots 1B, 3A, and 3B were cultivated to a depth of 6 to 8 inches with a mattock, and cleared of all vegetation, including roots, as far as possible. Parallel to each of these plots and separated by

a neutral strip 2 feet wide was an undisturbed plot. On account of deficient seed supply and unfavorable climatic conditions, few seedlings appeared on either the cultivated or the natural plots until 1919. By this time the soil on the cultivated plots had become packed. Vegetation had begun to reestablish itself, but, with the exception of a few plots, is was sparse. Seedling counts in August,

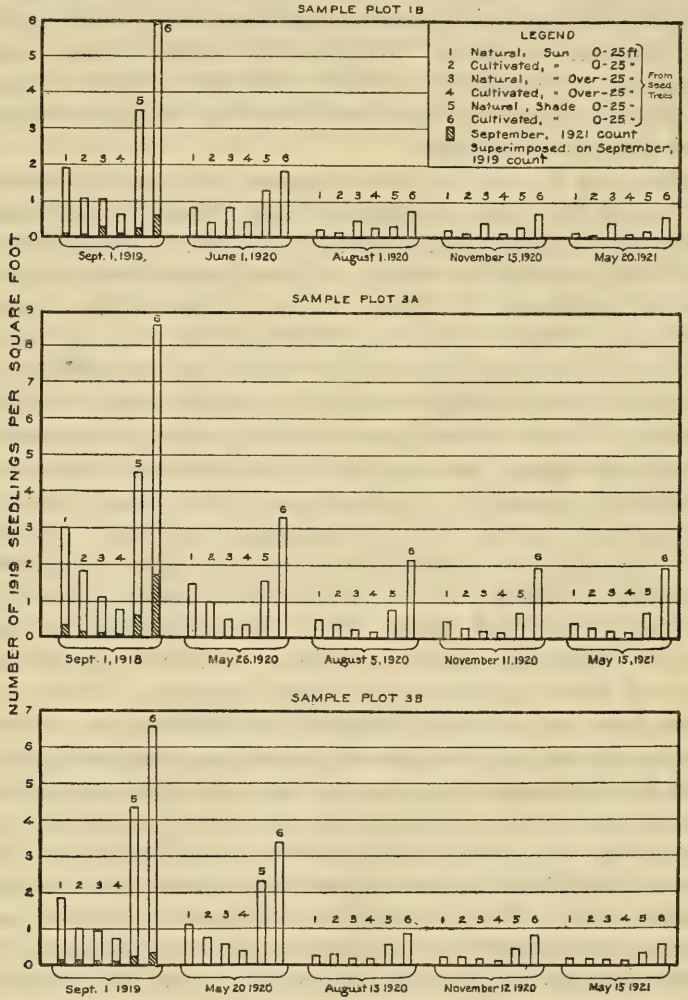


FIG. 4.—Relation of cultivation, shade, and litter to germination and survival.

1919, almost invariably showed a higher number on the natural than on the cultivated plots, except where the ground was heavily shaded by trees, or was covered with leaf litter or moderate amounts of vegetation. (See Tables 11 and 12 and Fig. 4.) Under the conditions last named the number of seedlings may be greater on the cultivated than on the natural plots. This indicates that, other things

being equal, germination is favored by loosening the soil, but that removal of ground cover or litter is detrimental. The explanation is simple, once the facts are clearly in mind. Cultivation, in the first place, tends to bring to the surface the clayey subsoil. It not only removes the vegetation which shades the soil and young seedlings, but also destroys the accumulation of leaf mold and litter resulting from fallen stems and leaves. The mold seems to be especially important, as it gives a loamy texture to the surface of an otherwise heavy soil. Observations show that where the grass is undisturbed for a number of years, a considerable amount of mold accumulates. Seeds bury themselves readily in this material; favorable conditions of soil moisture are preserved, at least during the rainy period; and the young seedlings are screened from the wind and hot sun by the taller herbage. Where the ground is shaded through the hot portion of the day, seeds germinate during the rainy season without being covered by soil. In the vicinity of trees the ground is usually littered with needles, which aid in keeping the surface moist. On the uncultivated plots, this litter was often too deep for good germination; but on the cultivated plots the old accumulation was turned under, thus adding organic matter to the soil and at the same time removing the excess of litter from the surface. Shade and litter usually go together, and apparently, within certain limits, the effects are silimar as far as germination is concerned. On some of the plots herbaceous vegetation has already come in to a considerable extent, but since the plants are of a different type from those on natural plots, it is difficult to make comparisons. In a few instances these plots have as many as or more seedlings than the adjoining natural ones.

Seedlings are in almost every case more numerous on the plots within 25 feet of seed trees than on those more remote. This subject has been discussed under "Seed supply." The distinction is made here primarily in order to place the shaded plots, all of which are within 25 feet of the trees, on a comparable basis with unshaded plots. Although distance from trees undoubtedly has an important bearing on survival, other factors must be considered.

Table 11 shows the percentage survival in various situations. In considering ultimate survival the plots shaded by trees half or more of the day may at once be eliminated, because it has been repeatedly demonstrated that western yellow pine seedlings will not thrive in such situations. Considering only the plots which are exposed to direct sunlight more than half the day, we find no consistent difference in percentage of survival, although the natural plots maintain the lead over the cultivated ones in actual numbers. Many of the natural plots are gradually losing their margin; there are, however, too many exceptions to recognize a definite trend in that direc-

tion. Another year's record may give decisive results; but it is anticipated that no thoroughly consistent relationship will be established, for the reason that conditions on the cultivated, as well as on the natural, plots are not uniform.

The effect of bringing the clay subsoil into the surface strata has been mentioned in the discussion of germination. Greenhouse tests have shown much slower growth in compact clay than in sandy and loamy soils. Field tests show a similar relation with respect to survival. We should expect the effects of cultivation to vary with the character of the soil. Where the loamy surface layer extends below the depth reached with the mattock, no injurious effects should result; but where the more clayey soil comes within 8 inches of the surface, or where the mattock has gone below the usual depth, the effect might be unfavorable.

Opposed to the influence of clay content stands the favorable effect of eliminating root competition. Undoubtedly the removal of herbaceous plants on a plot of 5 by 10 feet would tend to increase soil moisture in the lower strata reached by seedling roots in their second year. But some vegetation has come back on all of the plots (Pl. VI), and in many cases the luxuriance of these plants makes up for the deficiency in numbers. Moreover, nearly all the plots are within reach of tree roots, which would tend to utilize any surplus of soil moisture. On the whole, therefore, conditions of soil moisture are probably little, if any, better on the cultivated plots than on those bearing the original vegetation.

Winter protection is another factor. Other things being equal, the loss from winterkilling and ground heaving is greatest on bare ground. As previously stated, the cultivated plots are no longer bare, but the proportion of bare surface is greater than on the natural plots. Although no figures on late fall survival are available for 1919, the favorable moisture conditions in the fall of 1919 and early spring of 1920 make it safe to attribute the mortality between September, 1919, and May or early June, 1920, almost entirely to winterkilling and heaving. This conclusion is further strengthened by the fact that the winter was open, with a prevalence of rain instead of the usual deep snows. During the entire period there was no question of deficient soil moisture, except in so far as it may have been rendered unavailable by freezing. The winter of 1919–20 favored both winterkilling and ground heaving. Theoretically, a somewhat higher rate of mortality was to have been expected on the cultivated than on the natural plots. Average figures, however, show practically no difference. Surprisingly little loss from any cause occurred during the winter of 1920–21.

TABLE 11.—*Relation of cultivation, shade, and litter to germination and survival.*

SAMPLE PLOT 1B, FORT VALLEY, OLD CUTTING, CLOSELY GRAZED BY HORSES.

Date of examination.	Number of seedlings per square foot.						Survival per cent.					
	Sun.				Shade,[1] 0 to 25 feet.		Sun.				Shade, 0 to 25 feet.	
	0 to 25 feet.[2]		Over 25 feet.				0 to 25 feet.		Over 25 feet.			
	Natural.	Cultivated.[3]	Natural.	Cultivated.	Natural.	Cultivated.	Natural.	Cultivated.	Natural.	Cultivated.	Natural.	Cultivated.
Sept. 1, 1919	1.92	1.09	1.04	0.65	3.51	5.90	.....	.....	.....	.....	.....	.....
June 1, 1920	.85	.44	.84	.45	1.30	1.83	0.44	0.40	0.81	0.69	0.37	0.31
Aug. 1, 1920	.22	.15	.49	.30	.35	.73	.26	.34	.58	.67	.27	.40
Nov. 15, 1920	.22	.12	.45	.16	.32	.70	1.00	.80	.92	.53	.91	.96
May 20, 1921	.14	.06	.42	.14	.26	.64	.64	.50	.93	.88	.81	.91
Sept. 1, 1921	.07	.04	.31	.10	.23	.59	.50	.67	.74	.71	.88	.92
Survival, Sept., 1919, to Sept., 1921					.....	.....	3.6	3.7	29.8	15.4	6.6	10.0

SAMPLE PLOT 3A, FOREST SERVICE CUTTING, NO GRAZING; TALL, DENSE BUNCH-GRASS.

Sept. 1, 1919	3.01	1.84	1.10	0.77	4.52	8.56	.....	.....	.....	.....	.....	.....
Mar. 26, 1920	1.49	.99	.50	.38	1.56	3.30	0.50	0.54	0.45	0.49	0.35	0.39
Aug. 5, 1920	.48	.32	.21	.18	.77	2.12	.32	.32	.42	.47	.49	.64
Nov. 11, 1920	.40	.23	.16	.14	.68	1.88	.83	.72	.76	.78	.88	.89
May 15, 1921	.39	.23	.16	.12	.67	1.85	.98	1.00	1.00	.86	.99	.99
Sept. 1, 1921	.33	.14	.14	.08	.60	1.69	.85	.61	.88	.67	.90	.91
Survival, Sept., 1919, to Sept., 1921					.....	.....	11.0	7.6	12.7	10.4	13.3	19.7

SAMPLE PLOT 3B, FOREST SERVICE CUTTING, NO GRAZING; TALL, DENSE BUNCH-GRASS.

Sept. 1, 1919	1.88	1.00	0.94	0.71	4.33	6.53	.....	.....	.....	.....	.....	.....
May 20, 1920	1.19	.74	.53	.34	2.29	3.38	0.63	0.74	0.56	0.48	0.53	0.52
Aug. 13, 1920	.24	.28	.16	.15	.54	.86	.20	.38	.30	.44	.24	.25
Nov. 12, 1920	.21	.22	.16	.11	.44	.81	.88	.79	1.00	.73	.81	.94
May 15, 1921	.18	.18	.13	.10	.34	.62	.86	.82	.81	.91	.77	.77
Sept. 1, 1921	.13	.12	.09	.08	.22	.43	.72	.67	.69	.80	.65	.69
Survival, Sept., 1919, to Sept., 1921					.....	.....	6.9	12.0	9.6	11.3	5.1	6.6

[1] Plots shaded by trees one-half or more of the day are classed as shaded. Such plots also have considerable leaf litter.

[2] Distance from seed trees. All of the shaded plots are within 25 feet of trees while those in the sun are in many cases farther away.

[3] Cultivated with a mattock to a depth of 6 to 8 inches in 1914, removing all vegetation including roots as far as possible.

TABLE 12.—*Detailed record of seedling plots within sample plots 3A and 3B.*

[Bl= *Blepharoneuron tricholepis*, C= *Ceanothus fendleri*, Chen= *Chenopodium* sp., Cir= *Cirsium* sp., Er= *Erigeron* (small), F= *Festuca arizonica*, Lot= *Lotus wrightii*, Lup= *Lupinus hillii*, M= *Muhlenbergia montana*, Ox= *Oxytropis* (spreading), Pol= *Polygonum douglasii*, Sen= *Senecio spartioides*, Sit= *Sitanion* sp., Vic.= *Vicia americana*.
Order of symbols indicates relative abundance on each plot.
0.6= Density of cover, considering complete cover as 1.

IN SUN, DISTANCE 25 FEET OR LESS FROM SEED TREES.

Plot No.	Vegetation (1919).		Number of seedlings per 5 by 10 foot plot.							
	Natural plots.	Cultivated plots.	Sept., 1919.		May, 1920.		Aug., 1920.		Nov., 1920.	
			Natural.	Cultivated.	Natural.	Cultivated.	Natural.	Cultivated.	Natural.	Cultivated.
A2	0.6, Vic, Lup, M. F..	0.2, M, E, Lup.....	185	138	89	51	51	18	34	8
3	1.0, F, Vic, Lup, M..	0.7, Lup, Vic, M, Er...	102	66	43	23	6	8	6	8
4	0.9, F, Lot, M, Bl....	0.3, Lup, Lot, M, Bl...	80	14	45	11	23	10	23	8
10	0.8, F, M, Vic, Lup...	0.2, Lup, Vic, Lot, M..	235	150	121	113	17	29	17	23
B1	0.9, M, Bl, Lot.....	0.2, Lup, Lot, Vic.....	141	47	113	31	18	12	18	9
2	1.0, F, M, Vic.....	0.8, M, Lup, Sen.....	60	31	25	14	0	8	0	7
4	0.8, Vic, F, Lot, M...	0.6, Vic, Bl, M, Pol....	133	100	72	83	18	17	5	13
10	0.7, M, F, Vic, Lot...	0.1, Ox, Lot, Er, Cir ..	43	22	28	21	13	19	9	15

IN SUN, DISTANCE OVER 25 FEET FROM SEED TREES.

[1] A1	M, F, Er, C.....	0.2, M, Chen, Er.....	61	23	36	5	21	2	13	1
5	1.0, M, F, Bl, Sit.....	1.0, Bl, Sit, M. F.....	21	31	8	13	8	8	5	3
6	0.6, Lup, Sit, M, Vic..	1.0, Vic, Lup, Er, Cir	67	44	21	24	6	12	6	14
9	1.0, F, Bl, M, Lup....	0.6, M, Bl, Lup, Er....	72	56	36	34	8	15	8	10
B3	0.9, F, Bl, M, Vic....	0.8, Bl, Vic, M. Lup...	51	44	34	27	5	1	6	1
5	1.0, F, V, M, Lup....	0.7, M, Bl, Vic, Er.....	48	18	21	8	7	2	7	2
6	0.8, M, F, Lot, Lup..	0.3, Lot, Lup, M, Vic..	60	53	41	22	16	15	17	9
8	1.0, Vic, M, F, Bl....	0.5, E, M, Bl, Sit.....	29	27	10	12	3	11	3	11

IN SHADE ONE-HALF OR MORE OF DAY, ALL 25 FEET OR LESS FROM SEED TREES.

A7	1.0, Vic, Lup, Lot, M.	0.7, Lup, Lot, M.....	192	422	55	130	18	77	15	65
8	0.6, C, Lup, F, M.....	0.3, Lup, Lot, Vic, F..	260	434	101	200	59	135	53	117
B7	0.8, Vic, F, M, Lup...	0.5, Vic, Lup, Lot, Sit.	147	322	61	160	14	52	13	51
9	0.4, M, Bl, Sit, Ar....	0.3, Lot, Ox, M, Bl ...	286	331	168	178	40	34	31	30

[1] Burned brush pile on west two-thirds.

TABLE 13.—*Effect of cutting, herbaceous cover, and grazing upon survival and development of seedlings.*

Month and situation.	Basis, square feet.	Number 1919 seedlings.			Per cent large.	Grazing.		
		Total.	Per square foot.	Per acre.		Killed, per cent.	Injured, per cent.	
							Serious.	Moderate.
August, 1920:								
Open range—								
Stump patches	300	34	0.113	4,900	40	11	76	0
Natural areas	800	224	.280	12,200	7	21	2	0
Inclosure—								
Stump patches	200	17	.085	3,700	0	0	0	0
Natural areas	400	139	.347	15,000	14	0	0	1
November, 1920: [1]								
Open range—								
Stump patches	700	33	.047	2,000	58	[2] 0	55	18
Natural areas	800	147	.184	8,000	15	11	7	11
Inclosure—								
Stump patches	500	43	.086	3,700	7	0	0	0
Natural areas	400	112	.280	12,200	14	0	0	0
August, 1921: [1]								
Open range—								
Stump patches	400	10	.025	1,100	80	0	(3)	[3] 60
Natural areas	900	75	.083	3,600	46	3	(3)	31
Inclosure—								
Stump patches	400	1	.002	100	0	0	0	0
Natural areas	400	94	.235	10,200	44	0	0	3

[1] The natural plots are identical throughout, but new plots were selected for each examination in the stump patches.
[2] Although none were classed as dead, most of those classed as severely injured will not survive.
[3] The August record of grazing injury includes all seedlings showing evidence of injury at that time and probably injuries of the preceding fall and spring. Since this examination was made at the close of a period of vigorous growth, the injuries could not readily be classified as to severity or time of occurrence.

The mortality from September, 1919, to June 1, 1920, was less than during the much shorter period from June 1 to August 1, 1920. The bulk of the loss during this latter period is known to have occurred during the first two weeks of July, just prior to the beginning of the summer rains, the most critical drought of the year and in fact the only severe drought which the 1919 seedling crop had experienced. The foregoing relationships were repeated in 1921. Comparatively light losses occurred between August and November, 1920. So far the records clearly point to drought as the dominating factor, whether it is associated with clay content of the soil or with root competition. Conclusions as to the ultimate advantages or disadvantages of cultivation can be reached only after longer records are available, and will probably require a detailed analysis of each plot from the standpoint of soil and herbaceous vegetation, as well as seedling survival.

Denudation by overgrazing.—Regardless of the final outcome with respect to survival, the fact is established that the elimination of ground cover by deep cultivation under the conditions here described is unfavorable to germination. The reason is that on clayey soils the surface tends to pack and dry out more where the natural vegetation is removed than where it is left undisturbed. These conclu-

sions are strikingly confirmed under a different set of conditions in a treeless clay flat surrounded by virgin forest (Pl. VII, Fig. 1). This flat, which is virtually a small park about 150 yards in diameter, is typical of a common condition in the pine forests of this region. The surface is smooth, free from stones, and packed by tramping. Perennial grasses have given way almost entirely to "six-weeks grass," a short annual of small forage value. Clumps of *Senecio spartioides* and pingue (*Hymenoxys floribunda*), both unpalatable weeds, occupy about 15 per cent of ground surface. Counts in the middle of this opening in November, 1919, showed 13,000 seedlings of 1919 germination per acre; whereas near the south side, 75 feet from the edge of the timber, there were 25,000 per acre. The tendency of seedlings to group themselves in and around the weed clumps was so conspicuous that a 5 by 20 foot plot was charted

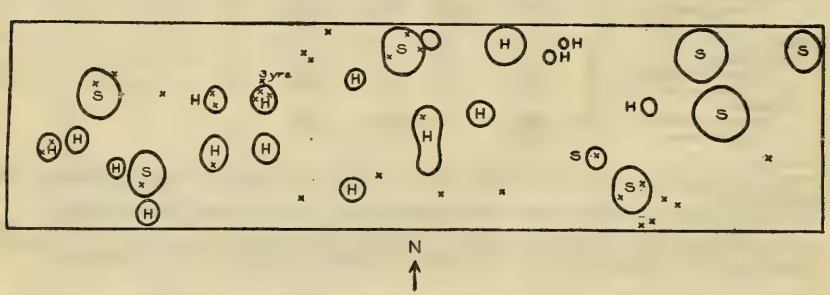


FIG. 5.—Location of western yellow pine seedlings with reference to ground cover. H=*Hymenoxys floribunda;* S=*Senecio spartioides;* ×=Western yellow pine seedling, 1919 germination.

to scale, showing the location of all seedlings and weed clumps (Fig. 5). It was found that 17, or 55 per cent, of the 1919 seedlings were in the weed clumps, which occupy approximately 13 per cent of the total ground surface. On this basis it appears, therefore, that the weed clumps are 8.2 times as favorable for germination of yellow pine seed as the intervening bare areas. One older seedling was found in the weeds and none in the open spaces. Another plot nearer the seed trees gave a ratio of 15 to 1 in favor of the weed clumps. A survey of about one-half acre in the middle of the park showed 37 seedlings of ages estimated at from 4 to 10 years, nearly all seriously injured by sheep. Of the total number, 19, or 51 per cent, were in weed clumps, which occupy not to exceed 15 per cent of the ground area, thus indicating that the chances for establishment and survival are roughly six times as great in the clumps as outside. The greater abundance of seedlings near weed clumps is explained, as in the case of the natural and cultivated plots, by the more favorable conditions for germination and early survival afforded by the weed

clumps, in providing soil cover and organic matter to relieve the clayey character of the soil (Pl. VII, Fig. 2). Another important factor, as will be shown later, is the protection which the unpalatable weeds afford against damage by grazing.

The above relation is not confined to the extremely heavy clay soils; it prevails generally on the volcanic soils throughout the yellow-pine type. It was first observed in the cinder region east of Flagstaff in 1908. Here the adverse conditions are not due to compactness of the surface, but, on the contrary, to excessive looseness and coarseness, and consequent inability to hold moisture. Where the cinders are deep, seeds rarely germinate except in dense shade, in leaf litter, or in bunches of grass or weeds. On such sites seedlings almost invariably occur in tufts of grass. Plate VIII, Figure 1, shows a seedling about 10 years old in a tuft of bluestem grass (*Andropogon scoparius*). The grass is dying out in the center of the tuft, and in a few years will have disappeared.

Plate VIII, Figure 2, shows a tuft of *Festuca arizonica* on a loamy clay soil in the region west of Fort Valley. No less than 12 seedlings of 1919 germination were counted in this tuft, most of them along the northern periphery. As may be seen from the photograph, the tuft is dying out in the middle. This is a common habit of the bunch grasses in this section. In old tufts the hollow spaces in the middle are from 4 to 6 inches in diameter, leaving only a fringe of live stems in the periphery. The interior is a mass of dead stems and roots, more or less decomposed and forming an excellent place for young seedlings to establish themselves. It should be noted also that the grass has been only partially grazed off. The remaining stems, about 6 inches tall, are too coarse to be relished by stock, and therefore stand through the winter and furnish protection to the seedlings.

LATER DEVELOPMENT RETARDED BY HERBACEOUS COVER.

As previously intimated, the protection afforded by herbaceous vegetation is not an unmixed blessing. After pine seedlings have passed through the first winter they do not need this protection (except against sheep grazing), but they do need the moisture and sunlight which are preempted by the larger plants. Studies during the summer and fall of 1920 demonstrated these relationships in a striking manner.

Stump patches.—When an area is logged there are left numerous bare patches formerly occupied by groups of trees. For convenience in reference these spots will be designated "stump patches," since the stumps of the felled trees always occupy the central portion. If the tree groups were large, the space underneath the crowns and for a distance of about 30 feet to the north will be found to be practically bare of grasses. If grazing animals are excluded, the

stump patches are quickly invaded by the more aggressive annuals and perennials of the weed type. The time required for the permanent grasses of the subclimax stage to establish themselves depends upon the amount of leaf litter and the extent to which they were shaded out. On two fenced areas the subclimax grasses, *Festuca arizonica* and *Muhlenbergia montana*, have in some instances regained complete possession in 12 years. More often, as shown in

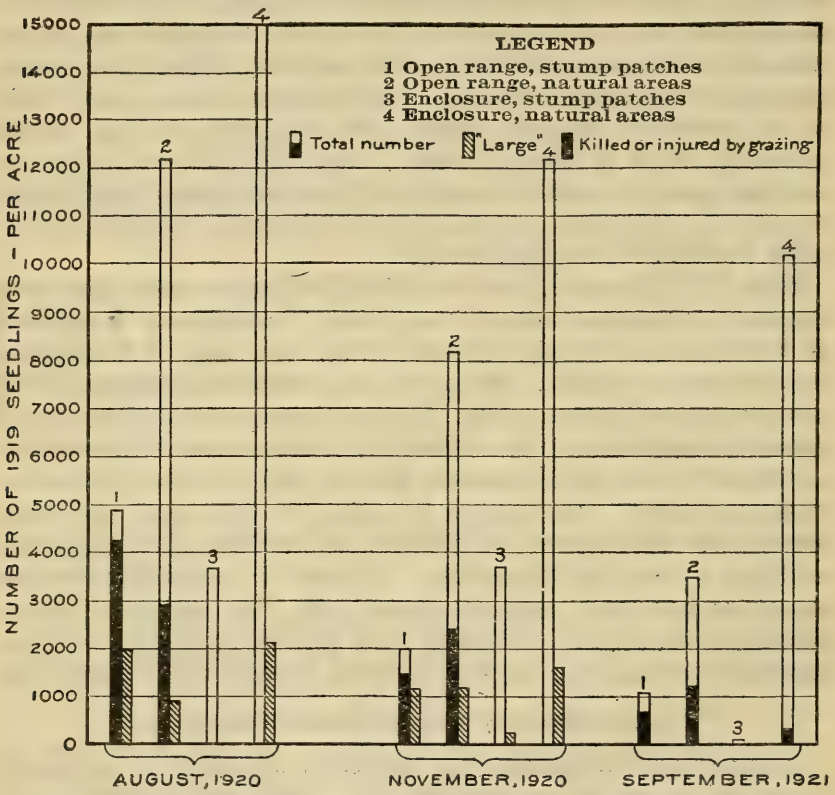
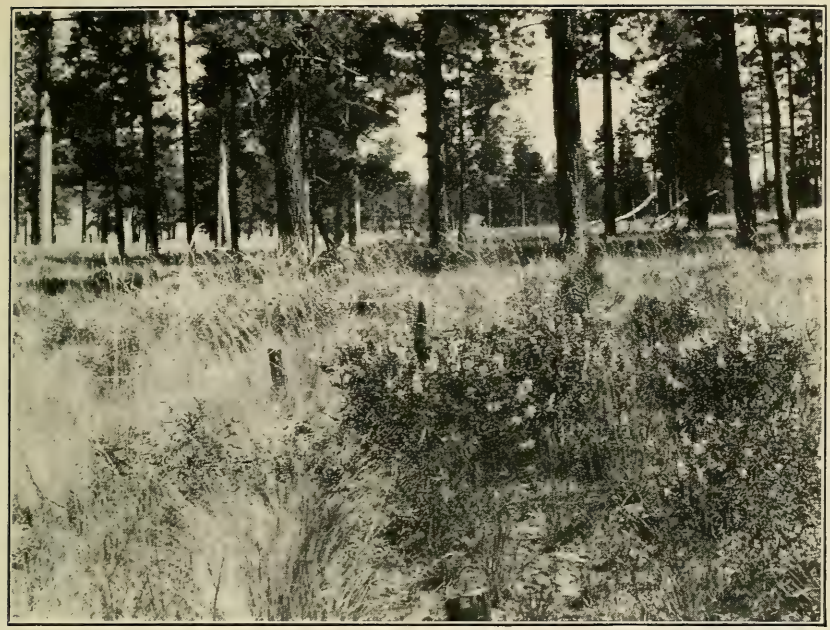


FIG. 6.—Effect of cutting, ground cover, and grazing upon seedling survival.

Plate IX, the stump patches are still occupied mainly by weeds, including such species as lupine (*Lupinus hillii*), vetch (*Vicia americana*), lambs' quarters (*Chenopodium album*), goldenrod (*Solidago nemoralis*), June grass (*Koeleria cristata*), and squirreltail (*Sitanion* sp.). Invariably the vegetation on stump patches, if ungrazed, is of extraordinary luxuriance, owing partly to the presence of decayed leaf litter, but mainly to the elimination of active tree roots. Under intensive grazing, particularly by sheep, the vegetation on the stump patches, being generally of a succulent type, is so closely cropped that from a distance the ground looks absolutely



F—49205A

FIG. 1.

F—43836A

FIG. 2.

FIGS. 1 AND 2.—TYPICAL SEEDLING PLOTS WITHIN SAMPLE PLOTS 3A AND 3B, AS THEY APPEARED IN 1920. LEFT, NATURAL; RIGHT, DENUDED IN 1914 BY CULTIVATING WITH A MATTOCK TO A DEPTH OF ABOUT 6 INCHES. PINE SEEDLINGS ARE LEAST NUMEROUS ON THE DENUDED PLOTS BECAUSE OF PACKING OF THE SOIL.

F—43860A

FIG. 1.—CLAY FLAT IN A VIRGIN STAND OF WESTERN YELLOW PINE. THE SOIL IS A STIFF CLAY, COMPACTED BY THE TRAMPING OF CATTLE AND SHEEP.

Overgrazing has destroyed the original vegetation, which has given way to "six-weeks grass" and noxious weeds. Seedlings are about six times as numerous in the weed clumps as in the open spaces.

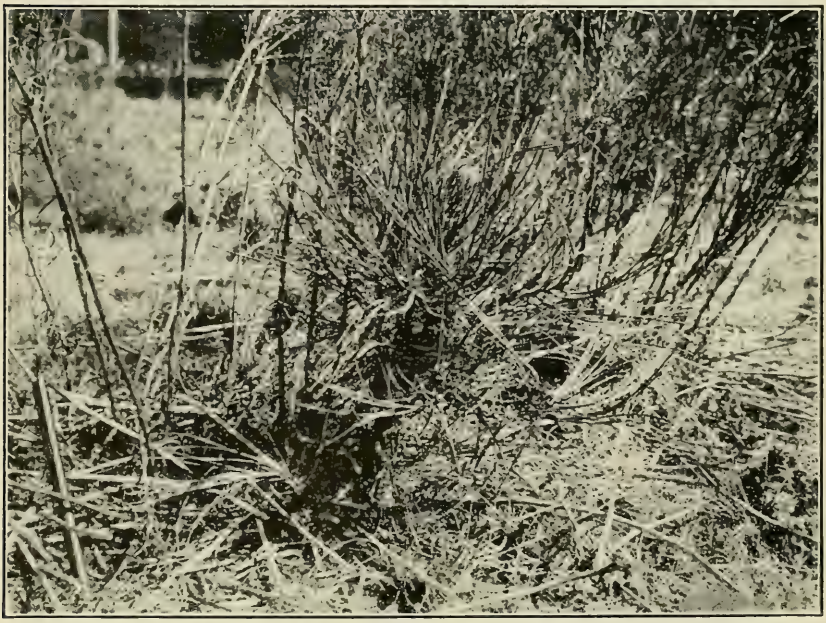


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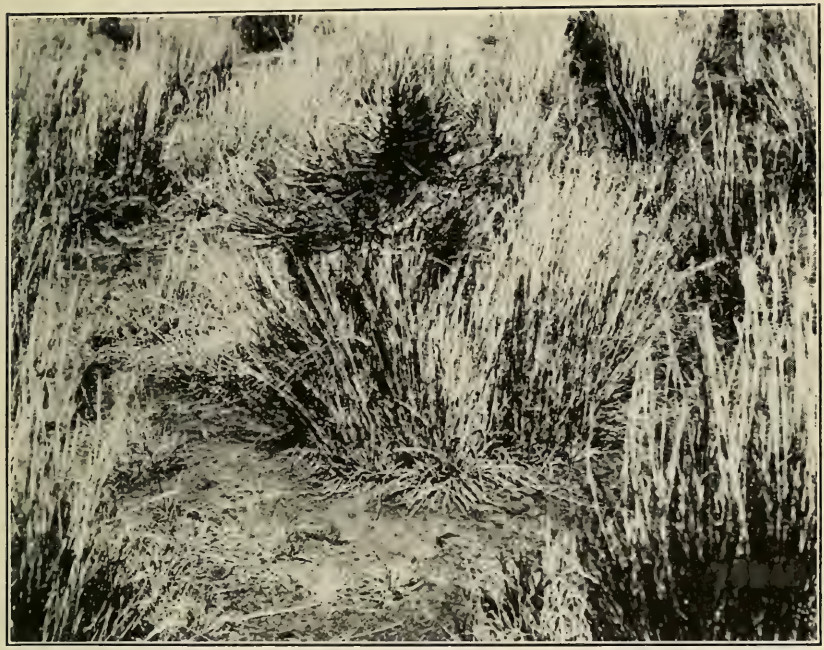
FIG. 2.—NEAR VIEW OF A CLUMP OF SENECIO SPARTIOIDES, SHOWING LITTER AT BASE, AND TWO PINE SEEDLINGS.

These weeds not only favor germination, but because of their unsavory character protect young seedlings against damage by grazing animals.



F—76640

FIG. 1.—PINE SEEDLING, ABOUT 10 YEARS OLD, IN A BUNCH OF ANDROPOGON SCOPARIUS, IN THE CINDER REGION NEAR THE LOWER LIMITS OF THE YELLOW PINE TYPE.

Seedlings rarely start in the bare cinders.

F—43876A

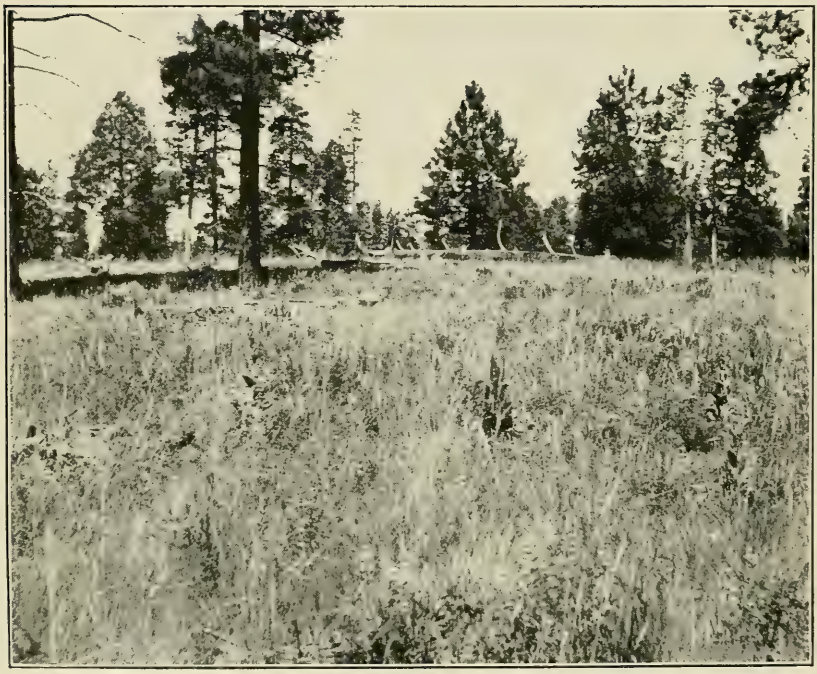
FIG. 2.—A BUNCH OF FESTUCA ARIZONICA IN THE FALL OF THE YEAR UNDER PROPER CATTLE GRAZING.

These tufts favor germination and early survival of pine seedlings, and also afford protection against sheep.

F—49213A

FIG. 1.—STUMP PATCH, 12 YEARS AFTER CUTTING, WITH BUNCHGRASS (FESTUCA ARIZONICA) IN THE BACKGROUND.

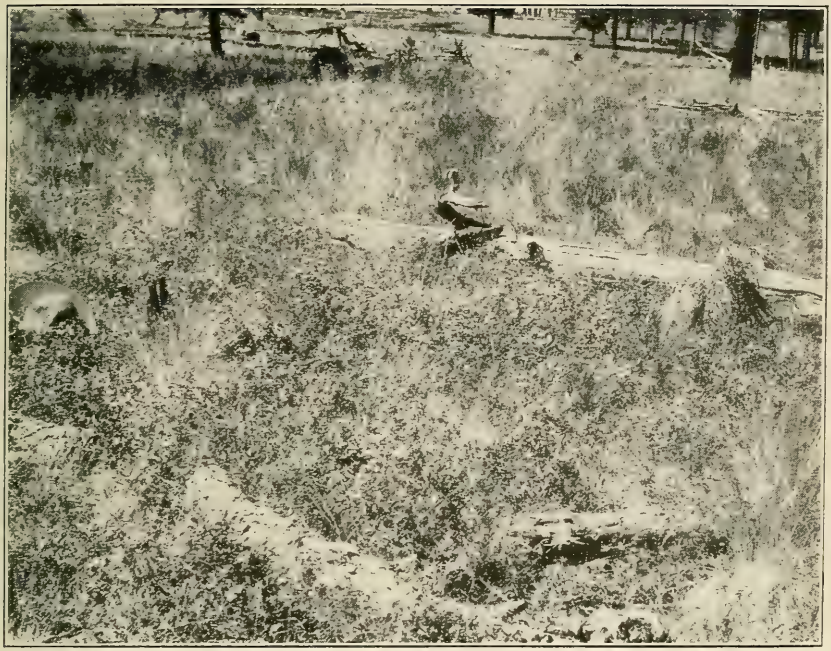
Pine seedlings make rapid growth here in the absence of damage by grazing because of the large amount of organic matter in the soil and the absence of living tree roots. Proper grazing is necessary to hold herbaceous vegetation in check.



F—49217A

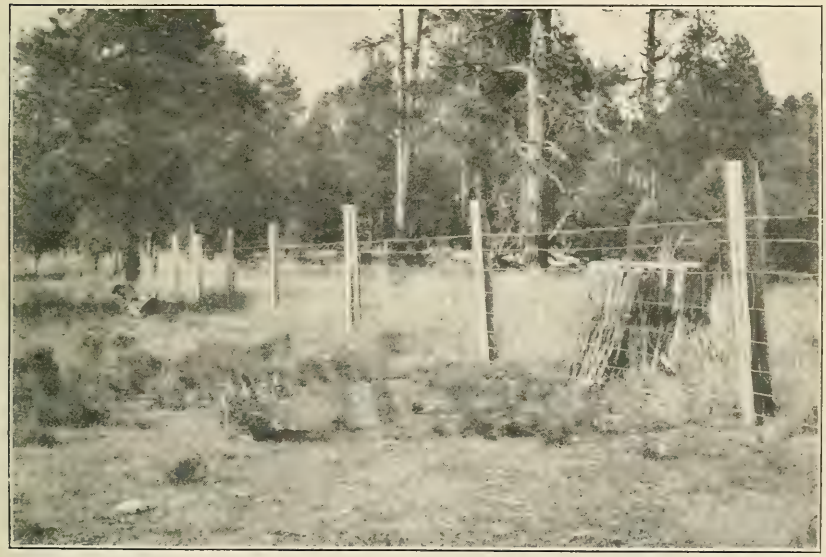
FIG. 2.—STUMP PATCH ON AN AREA LOGGED THE SAME YEAR AS THE ONE SHOWN IN FIG. 1, BUT PROTECTED AGAINST ALL GRAZING.

The luxuriant vegetation often chokes out pine seedlings.



F—49215A

FIG. 1.—LUXURIANT GROWTH OF VETCH (VICIA AMERICANA) AND RED-AND-YELLOW PEA (LOTUS WRIGHTII) ON AN UNGRAZED AREA.



F—48701A

FIG. 2.—PINGUS (HYMENOXYS FLORIBUNDA) AND SENECIO (SENECIO SPARTIOIDES), BOTH NOXIOUS WEEDS, FOUND CHIEFLY ON OVERGRAZED RANGE.

bare, save for occasional clumps of pingue (*Hymenoxys floribunda*), *Senecio spartioides*, or other obnoxious weeds which are not relished by any class of stock (Pl. IX).

In the foresummer of 1920 it was observed that pine seedlings in stump patches were generally much larger than those growing in adjacent bunch-grass areas. Later in the summer it also became apparent that the seedlings in the stump patches were subject to much more severe grazing damage than those in the bunch grass. In August and again in November counts were made on a number of plots in order to ascertain the true state of affairs. The results are shown in Table 13 and Figure 6. According to the August examinations, the plots on the open range showed 40 per cent of the seedlings on stump patches classed as large, but on adjoining bunch grass or natural areas only 7 per cent were thus classed.[9] The total number, however, was more than twice as great in the bunch grass as around the stumps. Within a near-by inclosure (sample plot 3A), where no grazing had been allowed for 10 years, the same general relation held with respect to total numbers; but with respect to size, it was strikingly reversed, there being very few large seedlings around the stumps, while 14 per cent of those at a distance from the stumps were classed as large. Outside the fence the damage by grazing amounts to 11 per cent killed and 76 per cent severely injured (total 87 per cent) on the stump patches, against 21 per cent killed and 2 per cent seriously injured (total 23 per cent) in the bunch-grass areas.[10] Only one seedling inside the fence showed any injury suggestive of grazing. This may have been done by deer. Examinations in November and again in the summer of 1921 show the same general relations as the August, 1920, examinations. In September, 1921, three-year seedlings on stump patches were from 3 to 4 inches tall, while seedlings of the same age in bunch grass were only from 1 to 2 inches tall.

On August 30 determinations of soil moisture were made in the four situations involved, namely, stump patches and natural or bunch-grass areas outside the inclosure, and corresponding situations inside, where all grazing had been excluded for 12 years. Table 14 gives the net available moisture content in each case. The results

[9] This classification is based upon ocular estimate and is therefore not exact, but is accurate enough to bring out general relations.

[10] In the counts of August and November, 1920, the stump patches showed a comparatively small number killed and a large number severely injured, while in the bunch-grass areas the reverse was true. The low percentage killed on the stump patches may be partially explained by the fact that the large seedlings are seldom cut off below the crown, and because of their great vigor they usually send out new shoots after being injured. It is quite likely, however, that, owing to the extremely close grazing, many seedlings had been entirely obliterated early in the season.

show the most moisture where there is least herbaceous growth and where the pine seedlings are largest.

TABLE 14.—*Effect of cutting and herbaceous cover upon soil moisture.*

SAMPLE PLOT 3A. AUGUST 30, 1920.

Location of sampling point.	Wilting [1] coefficient.		Available soil moisture.	
	6 inches.	12 inches.	6 inches.	12 inches.
Outside fence, grazed:	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Stump patches, sparse vegetation	12.0	16.8	5.0	3.8
Natural areas, bunch grass	12.2	16.9	2.8	2.5
Inside fence, ungrazed:				
Stump patches, dense vegetation	9.8	11.6	1.8	1.9
Natural areas, bunch grass	10.7	11.9	6.8	4.5

[1] All wilting coefficients in this investigation were determined at the Fort Valley Experiment Station by the wax-seal method of Briggs and Shantz (*2*). Oat seedlings were grown in ordinary glass tumblers in a greenhouse. The values given for available soil moisture are the net values after deducting wilting coefficient from total soil moisture.

NOTE.—The summer rains in 1920 were below normal, with the result that in many places they penetrated scarcely below 12 inches. On account of the surface packing due to overgrazing, the stump patches outside were probably most affected. In years of normal rainfall all of the samples would show a considerably higher moisture content, and the 12-inch samples would be higher than those at 6 inches.

The differences which have been pointed out lead to the following conclusions:

As to size, the striking superiority of the seedlings on stump patches outside the inclosure is due mainly to the fact that they have but little competition for soil moisture, since the ground is almost bare of other vegetation, even the absorption by tree roots having been eliminated. Organic matter in the surface soil strata resulting from the decay of leaf litter is also a contributing factor. On the other hand, stump patches within the inclosures where no grazing is permitted bear seedlings which are distinctly below normal size, because of the fact that in these situations the herbaceous vegetation is much denser and more luxuriant than elsewhere, thus subjecting the pine seedlings to severe competition for soil moisture and in a lesser degree for light.

In point of numbers, the stump patches are during the first two years after germination distinctly below adjacent natural-grass areas, both inside and outside the inclosure. Where grazing has been going on this difference is due in a large measure to greater damage by sheep on the stump patches than in the bunch grass, as a result of extremely close grazing in the former situations. Absence of ground cover would also tend to affect germination and early survival adversely, for reasons previously explained. Within the inclosure, however, where no grazing damage exists, and where vegetation is denser on the stump areas than elsewhere, the above explanations obviously do not hold. In this case, as in the matter of size, the strikingly inferior results on the stump patches must be attributed to suppression by the dense growth of weeds and grass. Unfortu-

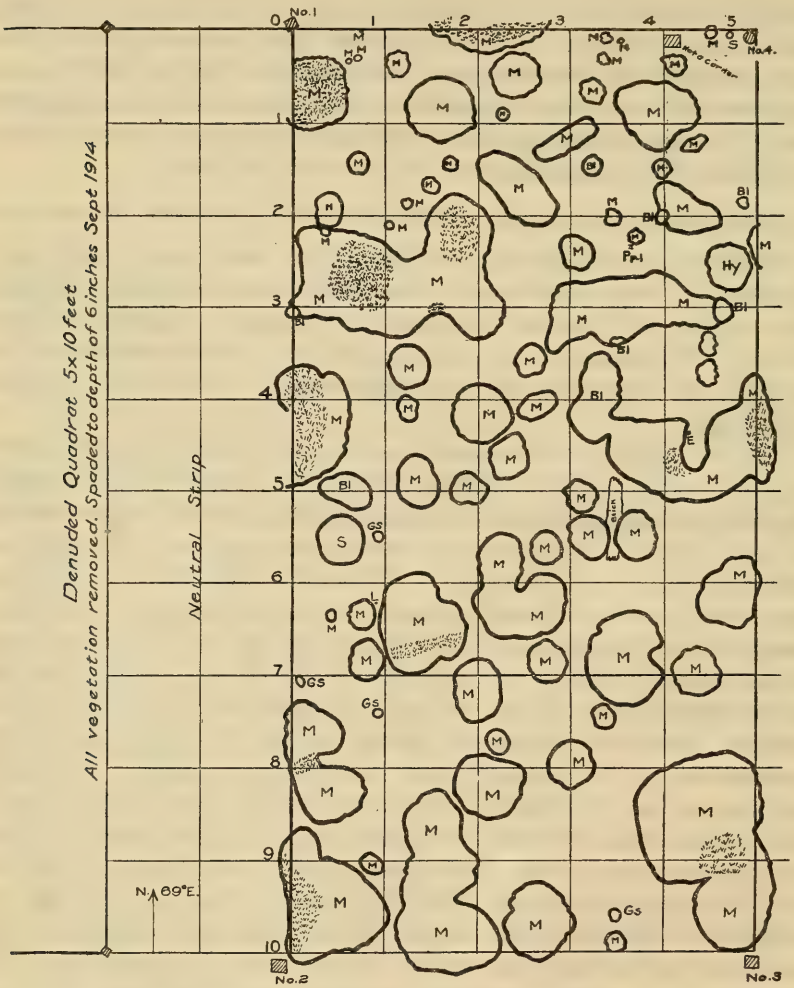
nately no figures on the original density of seedlings on stump patches are available. It is a significant fact, however, that on the plots examined in August, 1920, following the dry period of June and first half of July, 78 seedlings were recorded as dead against only 17 living, indicating a loss of 82 per cent, whereas nearby plots in typical bunch grass showed only 44 per cent dead.

PLANT SUCCESSION IN RELATION TO REPRODUCTION OF WESTERN YELLOW PINE.

Another phase of the subject, which has been studied only incidentally, is plant succession. The most casual observations show that appreciable changes in herbaceous vegetation take place after cutting. The question is, Can any definite laws be established regarding the association of pine reproduction with stages of plant succession?

First, it should be understood that the disturbances brought about by a properly regulated cutting in western yellow pine are much less violent than in the case of a clear cutting, or a moderate cutting in denser stands. Unless natural conditions have been seriously disturbed by fire or overgrazing, the herbaceous vegetation in the openings, even in a virgin forest, is already in its highest stage of development; that is, the subclimax stage, regarding the trees as climax stage of the series. Cutting, as practiced by the Forest Service, removes about three-fourths of the volume and somewhat less of the crown canopy. Removal is confined almost entirely to mature and overmature trees which normally occur in even-aged groups. The greatest changes are in these felled groups, which, after cutting, leave open spaces relatively bare of vegetation, or in some cases occupied by shade-enduring plants belonging to the lower stages of succession. Logging operations also bring about partial or complete denudation on small localized areas such as roads and landings. Considerable patches are covered by débris, which is sometimes left practically as it falls, sometimes scattered, and sometimes piled and burned. In the first two instances the herbaceous vegetation may suffer a temporary reduction in density, but the composition is not greatly changed. It is only where there has been appreciable disturbance of the subclimax association, as on stump patches, burned brush areas, and overgrazed areas, that succession comes into active play.

Sample plots 3A and 3B have afforded a good opportunity to observe the changes in herbaceous vegetation after cutting, with grazing eliminated. Beginning in 1914, five years after the original establishment of the plots, 20 natural and the same number of denuded quadrats were established. Two of each were charted, and complete lists were made of the species on all other plots. Figures 7 and 8 show the charts of a natural and a denuded quadrat in

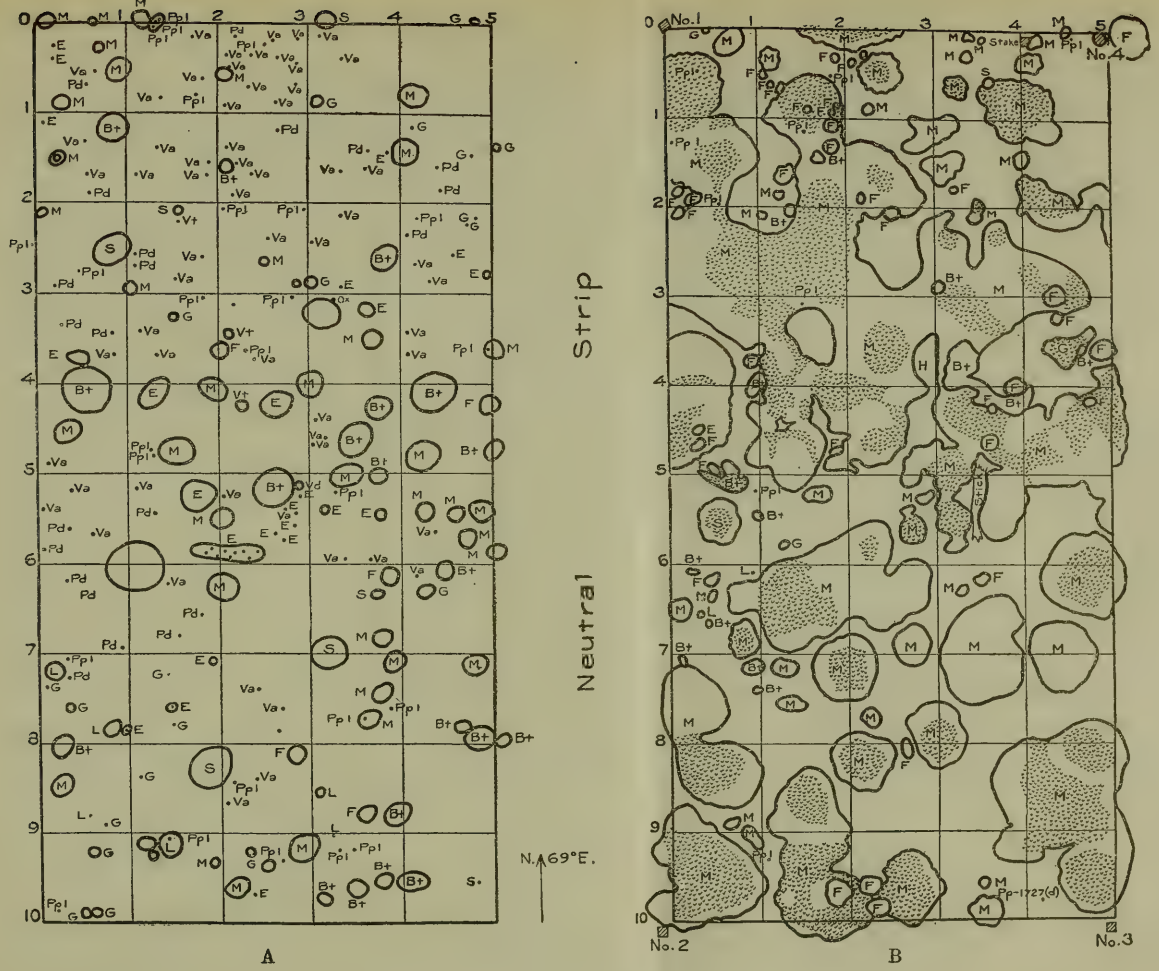


LEGEND

Bl Blepharoneuron tricholepis
E Eriqeron
L Lupinus
M Muhlenbergia montana
Pp-1 Pinus ponderosa-1 year old
Hy Hymenopappus
Grass tuft dead, or nearly so
S Sitanion

Corner No. 1 Plot laid off from this point. Other corners numbered in consecutive order. Exact location of each corner marked by head of nail driven into stake.

FIG. 7.—Mc-2 Fort Valley seedling plot 5-E, S 3-A. Dimensions of squares 1 by 1 foot. Mapped by G. A. Pearson, September 22, 1914.



LEGEND

Ox	Oxytropis sp.	L	Lupinus pauciflorus.
Vd	Villanova dissecta	M	Muhlenbergia montana
Bt	Blepharoneuron tricholepis.	Pd	Polygonum douglasii.
d	Dead.	Ppl	Pinus ponderosa · 1 year old
E	Erigeron sp.	S	Sitanion sp.
F	Festuca arizonica	Va	Vicia americana.
G	Grass, unidentified genus	Vt	Verbascum thapsus.
H	Hymenopappus sp.	1727	Number of pine seedling

▨ Corner of plot. Plot laid off from Corner No. 1; other corners numbered in consecutive order; exact location of each corner marked by head of nail driven into stake.

▒ Grass tuft dead, or nearly so.

FIG. 8.—Mc-2 Fort Valley seedling plots 5–E, S 3–A. Dimensions of squares, 1 by 1 foot. *A*, "Denuded"—All vegetation removed by spading to depth of 6 inches, September, 1914. Mapped by G. A. Pearson, October 21, 1919. *B*. "Natural"—Mapped by G. A. Pearson, September 22, 1914. Remapped by G. A. Pearson and F. W. Haasis, October, 1919.

1914 and 1919. A comparison of present conditions inside and outside the fenced areas also gives a good idea of the effects of grazing. The present composition inside the fence is indicated by Table 12. It will be seen from this that the dominants in the subclimax associations are the two bunch grasses, *Festuca arizonica* and *Muhlenbergia montana*.

The following stages[11] of development in plant cover are recognized, No. 1 representing the lowest and No. 4 the highest.

STAGE OF DEVELOPMENT.	CHARACTERISTIC SPECIES.
1. First weed stage: Completely denuded and packed areas such as roads and severely overgrazed areas. (Pl. IX, Fig. 1.)	*Polygonum douglasii.* *Erigeron divergens.* *Bouteloua procumbens* (annual). *Sporobolus ramulosus* (annual).
2. Second weed stage: Cultivated plots, and stump patches. (Pl. IX, Fig. 2.)	*Vicia americana.* *Lotus wrightii.* *Sitanion* sp. *Hymenoxys floribunda.* *Senecio spartioides.* *Koeleria cristata.* *Artemisia mexicana.* *Artemisia dracunculoides.*
3. Subclimax stage: Normal openings unaffected by overgrazing or other disturbing factors. (Pl. III.) In some localities the subclimax stage is represented by bunch grasses, in others by turf forming grasses such as grama or wheat grass. Since these grasses are associated with the pine and are essentially a part of the forest, they might, from this point of view, be placed in the climax stage. But the fact that they are always shaded out where the pine is dense seems to justify the classification here used.	*Festuca arizonica.* *Muhlenbergia montana.* *Blepharoneuron tricholepis.* *Lupinus hillii.* *Sporobolus interruptus.* *Agropyron smithii.* *Bouteloua gracilis.* *Andropogon scoparius.*
4. Climax stage: Areas occupied by western yellow pine. (Pl. XIV, Fig. 2.)	*Pinus ponderosa scopulorum.*

A characteristic difference between the vegetation inside and that outside the inclosure is the absence outside of vetch (*Vicia americana*) and the red-and-yellow pea (*Lotus wrightii*). Both of these plants are considered excellent sheep feed and are therefore very closely grazed outside the fence. Although casual observations suggest complete extermination, it is more probable that the perennial roots still persist, but that the stems are repeatedly eaten off before they attain sufficient height to become noticeable. These species became prominent on the fenced plots within five years after the exclusion

[11] Adapted from Sampson's Plant Succession in Relation to Range Management (23).

of stock and increased their abundance during the second five-year period. Plate X, Fig. 1 shows a patch of ground almost completely covered by vetch. It appears highly probable that excessive damage to pine reproduction on the bunch-grass range in this locality is in a large measure due to the scarcity of these and other palatable sheep forage plants. Observations indicate that the vetch and red-and-yellow pea, though most abundant in the lower stages, may be permanent members of the subclimax associations.

Another characteristic difference due to grazing appears in the second weed stage. Most of the representatives of this stage are palatable to sheep; hence they are cropped very closely, especially on stump patches, where they make luxuriant growth. Overgrazing in this stage commonly causes a reversion to the first weed stage. The two "six-weeks" grasses (*Sporobolus ramulosus* and *Bouteloua procumbens*), pingue (*Hymenoxys floribunda*), and *Senecio spartioides* are common indicator species of such retrogression (Pl. X, Fig. 2). The two last-named species are members of the second weed stage which not only persists but flourish under overgrazing because they are rarely eaten by stock when other forage is available. The second weed stage may, because of its great luxuriance, become distinctly unfavorable to yellow pine reproduction. (Pl. IX, Fig. 2.)

Although the study of succession has not been carried out in sufficient detail to disclose the whole story of the development of herbaceous vegetation, enough is known of the relation to western yellow pine reproduction to warrant the following conclusions:

Reproduction of western yellow pine in this region may occur in any stage of the series. The chances for success are best in the first weed stage or at the beginning of the second weed stage, when there is sufficient cover to assist germination, but not enough to subject the seedlings to severe competition for moisture and light. If moderate amounts of dead material, such as leaf litter or branches, can be provided as a soil cover, the entire absence of growing plants is preferable. During the second weed stage there is danger, especially on the richer soils, that the herbaceous plants will suppress the pine seedlings. On the whole, the subclimax stage is less favorable than the first weed stage, but is at least as favorable as the second weed stage. According to the usual conception, succession is associated with soil building; that is, the lowest stage occurs on the poorest soil and paves the way for the next higher stage by building up the soil. Sampson (*23*) has shown that on areas subject to rapid erosion plant retrogression and soil deterioration go hand in hand and that before the subclimax stage can come back the soil must be built up through the weed stages. This relation is the exception rather than the rule in the yellow pine forests of the Colorado Plateau. Here retrogression from the higher stages of plant cover is seldom

accompanied by serious soil deterioration, excepting on steep slopes, which occupy but a small portion of the total area.[12] Moreover, western yellow pine does not require a fertile soil for reproduction, provided the physical conditions are favorable.

HERBACEOUS PLANTS AS INDICATORS OF POSSIBILITIES FOR REPRODUCTION.

The greater portions of the areas to be restocked with western yellow pine are in the subclimax stage. This stage is represented in various localities by various plant societies, depending upon the soil and other factors. The key species in the most common subclimax associations on the Colorado Plateau are *Festuca arizonica*, *Muhlenbergia montana*, *Agropyron smithii*, *Sporobolus interruptus*, *Bouteloua gracilis*, and *Andropogon scoparius*. In the sample plots 3A and 3B, which are characteristic of the bunch-grass type of the Coconino and Tusayan Forests, *Festuca arizonica* and *Muhlenbergia montana* occur more or less in mixture, the former predominating on the finer clay soils and the latter on the more stony or gravelly soils. On the most prominent rock outcrops *Andropogon scoparius* is usually present and often becomes dominant.

The survey of sample plots 3A and 3B shows that yellow-pine reproduction is progressing better on the areas where *Muhlenbergia montana* predominates than where *Festuca arizonica* predominates, and that the very best reproduction occurs in the limited spots of *Andropogon scoparius*. Although these differences are due primarily to the influence of the soil rather than to direct effects of the grasses, both factors appear to be important. *Festuca arizonica*, for example, thrives best in the finer clay soils in which yellow pine reproduces with greatest difficulty; but the presence of this plant, which on such sites becomes very tall and dense, creates still more adverse conditions. *Muhlenbergia montana* predominates on the more stony or gravelly soils, which in themselves are more favorable to pine reproduction, but on such sites the stand of grass is much lighter than the *Festuca arizonica* stands. Thus we have the two favorable factors, porous soil and light grass, associated on one side, and the two unfavorable factors, heavy soil and tall dense grass, on the other. Although the basic elements are not clearly differentiated, it is believed that the relative dominance of three grasses mentioned above may be employed as an index of possibilities for reproduction of western yellow pine, the relative degree of favorableness being in the order named. Until further studies are made, the application of this relationship is restricted to soils of basaltic derivation on the Coconino Tusayan National Forests.

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[12] This applies to the Colorado Plateau. In certain other regions erosion is an important factor.

CUTTING.

Forest cover, as the term is understood by foresters, involves many factors. In studying the effects of cutting or other disturbances affecting the density of the crown canopy, we have to consider on one hand the shelter to young seedlings and on the other the possible detrimental effects of too much shade and root competition.

SHELTER AFFORDED BY TREES.

NEAR THE TREES.

That seedlings receive shelter from older trees in the forest has been recognized since the beginning of forestry. Forest cover cuts off isolation and thereby reduces day temperatures; but by retarding losses through radiation, it tends to raise night temperatures. Soil temperatures is lower beneath the crown canopy, with the exception of surface temperature, which may be slightly higher at night. Reduced insolation and wind movement decreases evaporation from the soil and the transpiration of plants. This tends to conserve soil moisture, particularly at the surface. Leaf litter, by by forming a soil mulch, adds to the above effects. Undergrowth, which normally draws considerable moisture from the soil, is held in check by the shade of the trees.

It is a matter of common observation that western yellow pine germinates most abundantly in the immediate vicinity of older trees. Seed supply is only one of the factors here involved. Young seedlings are most numerous in a zone which corresponds roughly to the area shaded in summer by the tree crowns from 11 a. m. to 3 p. m., modified to some extent by the distribution of leaf litter. This area, which may be characterized as the zone of maximum influence, extends farther to the north and east than in other directions; on the south side it almost coincides with the outer edge of the tree crowns. Solar radiation apparently is the dominant factor, although wind, which blows prevailingly from the southwest, is probably also important. A prominent feature which marks the zone of maximum influence is the scarcity of typical sun vegetation. Under the crown canopy, and from 20 to 40 feet to the north and shorter distances in other directions, the grasses which predominate in the open spaces are to a large extent supplanted by broad-leaved plants. Under single trees or small, high-crowned groups, however, the grasses often come almost up to the trunk.

Notwithstanding the abundant initial establishment of seedlings in the zone of maximum shelter, survival is poor. After the second or third year they begin to pine away, and few live to be 5

years old. The result is that in stands where reproduction is characterized as complete, blank spots remain around the tree groups, their outlines coinciding with those of the grassless areas described above. (Pl. XI.) As in the case of grass, pine seedlings grow almost up to the base of the tree trunks if the crowns are high above the ground. This points to isolation rather than root competition as the dominant factor, although root competition is no doubt important. This conclusion is strengthened by the fact that the relations described above are brought out most strongly in stands where the group arrangements is most highly developed, and are scarcely apparent where the trees are evenly distributed.

IN OPENINGS.

Under the present limitations of silvicultural practice, western yellow pine reproduction must be secured practically without the direct shelter of older trees; that is, in the openings. In virgin stands the trees exert an appreciable influence upon atmospheric conditions, even in the treeless spaces from 50 to 100 feet or more away. Investigations at the Fort Valley Experiment Station have shown that in openings in a virgin stand, 50 to 75 feet from the nearest trees, temperature, wind, and evaporation were appreciably modified, as compared with conditions in an open park a quarter of a mile distant. The results of this investigation (*17*) are briefly reviewed here.

Maximum air temperatures average 0.9° F. lower, and minimum temperatures 6.4° F. higher, in the forest than in the open. The great difference in minimum temperature is in this instance due partly to air drainage, since the park lies slightly lower than the forest, both receiving the drainage from the San Francisco Mountains which rise about 5,500 feet above the instrument stations. It is probable, however that the forest, in addition to checking radiation from the ground, also tends to deflect the cold air currents descending from the mountains. In another locality removed about 12 miles from the immediate influence of the mountains, a clear-cut area showed minimum temperatures averaging 2.1° F. lower than an adjoining virgin stand. In this case the two areas were practically identical as to topography. During the growing season the soil temperature at a depth of 2 feet was about 5° F. lower on the north side of a group of trees in the forest than in the park. Annual wind movement in the forest was only 51 per cent of that in the park. Evaporation from a free water surface during the growing season was 30 per cent less in the forest than in the park. The above conclusions are in general confirmed by European investigations.

Obviously the effect of a cut-over stand is less than that shown in the above investigation. In June and July, 1912, it was found that in a forest in which about 75 per cent of the stand had been removed, wind movement was 61.8 per cent of that in the open park, whereas in a virgin forest it was only 52.3 per cent of that in the park. No comparisons of temperatures are available, but it seems safe to assume that, except in situations subject to strong air drainage, temperature extremes are seldom modified more than a degree or two.

Recent investigations have placed greater emphasis upon variations within the forest itself due to local variations in forest cover. In this connection it should be borne in mind that the trees in the virgin western yellow pine stands of this region [13] are not uniformly distributed, but are mostly arranged in groups from 50 to 75 feet in diameter, separated by somewhat larger openings. In cut-over stands the tree groups are fewer and the openings larger (Fig. 1).

A rough index of solar radiation is furnished by soil temperatures. Although soil temperature does not represent the total radiation, it is of value for comparative purposes. Table 15 shows the mean soil temperature at a depth of 1 foot under cover of a group of veterans, under partial shade, and in an opening which is reached by shadows only early in the morning and late in the afternoon. During the winter months the difference is slight, because the blanket of snow tends to equalize the temperature. When the ground is bare of snow, however, there is a pronounced difference, which is greatest in May, June, September, and October, the months with the greatest percentage of clear days. In May the soil was 12.2° F. warmer in the opening than in the shade of the groups of pines.

TABLE 15.—*Soil temperature at a depth of 1 foot in the yellow pine forest.*

Month.	Cover.	Partial shade.	Open.	Month.	Cover.	Partial shade.	Open.
	° F.	*° F.*	*° F.*		*° F.*	*° F.*	*° F.*
January	31.4	32.1	33.5	September	54.4	58.0	63.6
February	29.9	30.4	31.1	October	48.0	51.9	58.0
March	34.4	35.2	35.6	November	37.3	39.2	41.1
April	39.6	41.6	46.7	December	33.1	32.7	32.7
May	44.4	47.9	56.6				
June	56.1	58.6	65.4	Mean, annual	43.7	45.7	49.6
July	58.4	60.2	65.3	Mean, May–Oct	53.1	56.2	62.5
August	57.4	60.3	65.9				

Surface temperatures bring out the above effects still more strikingly. During December, 1918, the mean maximum temperature at the surface of the soil in the opening was 20.6° F. higher than in the shade of the pines. On June 11, 1920, the surface soil at a

[13] This applies particularly to the Coconino and Tusayan Forests. In other localities the distribution is more uniform.

depth of one-fourth inch in full sun at Fort Valley registered 123.8° F. at 2 p. m., whereas in the shade of a group of tall pines it registered only 69.8° F. Differences of this magnitude are not at all uncommon.

A similar relationship was exhibited by the transpiration of yellow pine and Douglas fir seedlings. Those exposed to the greatest amount of sunlight invariably showed the highest loss of water. It is reasonable to suppose that a reduction of transpiration might save seedlings from death during critical periods of drought. On the other hand, the probabilities are that this saving of water is accomplished at the expense of growth. Moreover, many of the seedlings so situated as to be shaded by trees during any considerable portion of the day encounter competition for soil moisture from the roots of older trees; thus they may fare worse from the standpoint of moisture than seedlings exposed to full sunlight but beyond the influence of tree roots. Bates's (*1*) investigation of windbreaks throws additional light on this subject. He found that for a distance equal to from one-half to the total height of a windbreak, on the north side, the yield of field crops was below normal, due to shading, and that sapping carried this effect to about one and one-half times the height of the trees. Beyond this point the yield was above that of unprotected fields for a distance equal to from 4 to over 10 times the height of the windbreak. Although the arrangement of trees in a cut-over stand would not give such pronounced effects as a continuous windbreak, it seems fair to assume that the same principles would apply.

EFFECT OF CUTTING ON SOIL MOISTURE.

AREAS OF STRONG ROOT ACTIVITY VS. AREAS OF NO ROOT ACTIVITY.

When a tree is removed from the stand, the water loss resulting from increased insolation and wind movement is in a greater or less degree offset by stopping the consumption by the tree itself Whether the net result is a loss or a saving of soil moisture is a matter of importance. With the object of answering this question, experiments were carried on at the Fort Valley Experiment Station in 1919 and 1920.

In 1919 soil-moisture tests were made in areas occupied by the roots of living trees (site 1) and in areas containing the dead roots of trees felled two years previously (site 2). Excessive grazing had reduced the stocking of herbaceous vegetation on both sites to below normal density, and continued cropping for the most part kept it from growing more than a few inches tall. Lupine became luxuriant during July and August, but declined early in September from the effects of a leaf disease.

The area of root activity was represented by two sampling points, one north and one south and east of a large group of trees. Both were well outside the crown cover, beyond the zone of dense shade and leaf litter, at a distance of about 30 feet from the base of the nearest tree. The samples representing the area of no tree roots

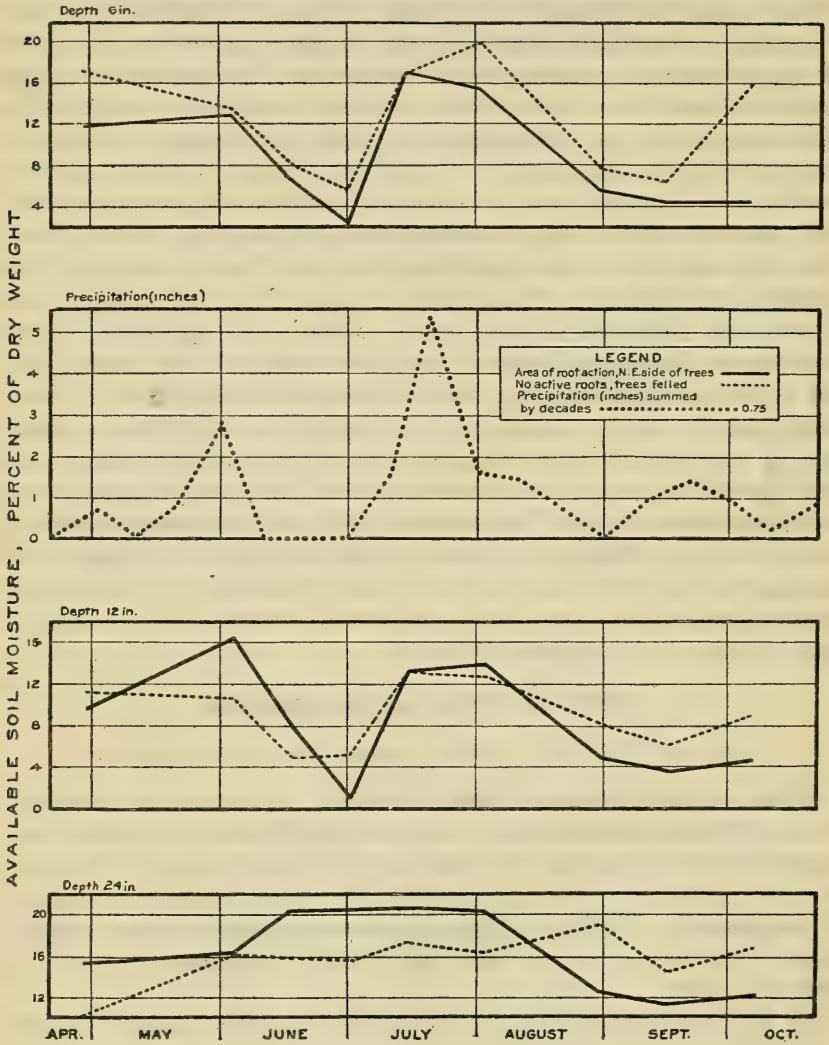


FIG. 9.—Effect of cutting upon soil moisture, 1919.

were taken at two points about 30 feet east of two large stumps and 75 feet from the nearest living trees. Abnormally heavy rainfall throughout the season prevented securing decisive data, but nevertheless the results as shown in Table 16 and Figure 9 are significant.

In the 6-inch series, the samples taken on site 1, within the area permeated by active tree roots, are consistently lower in moisture

content than those taken on site 2, in the area near the felled trees. The fact that this relation obtained on May 1 and on August 1, when the soil in both situations was thoroughly saturated, suggests that the soil in site 2 has a higher capacity for water than that of site 1. However this may be, it is significant that this lead was maintained through the most active growing period, and that it increased during the periods of least rainfall, in June and September.

TABLE 16.—*Effect of cutting upon soil moisture, 1919.*

Depth and location.	Wilting coefficient.	Available soil moisture in percentage of dry weight.								
		Apr. 28.	June 3.	June 17.	July 1.	July 15.	Aug. 2.	Aug. 30.	Sept. 15.	Oct. 6.
Depth 2 inches:										
Area of root action, near live trees—										
Northeast	8.3	14.3	19.2	7.4	1.9	31.2	24.3	10.4	7.9	14.7
Under crowns	8.6	32.9	38.9	16.6	5.1	30.6	32.2	19.8	.....	.....
No active roots, trees felled.	7.8	15.5	26.6	2.7	5.6	21.1	22.5	9.6	13.8	22.5
Depth 6 inches:										
Near live trees—										
Northeast	13.5	11.9	12.8	6.5	2.2	17.0	15.3	5.4	4.3	4.4
Under crowns	12.0	12.3	16.0	.....	4.3	17.8	20.8	7.4	.....	.....
No active roots, trees felled.	11.3	17.1	13.5	8.2	5.6	17.0	19.8	7.7	6.4	15.7
Depth 12 inches:										
Area of root action, near live trees, northeast	17.1	9.7	16.5	7.9	1.1	13.4	14.1	5.0	3.8	4.8
No active roots, trees felled.	14.8	11.4	10.7	5.0	5.4	13.5	12.9	8.5	6.4	9.3
Depth 24 inches:										
Area of root action, near live trees, northeast	16.3	15.3	16.2	20.4	.....	20.7	20.3	12.4	11.4	12.0
No active roots, trees felled.	13.6	10.3	16.1	16.1	15.6	17.2	16.4	19.0	14.5	16.7

In the 12-inch series, site 1 certainly is not handicapped at the beginning of the season. On June 1 and June 15 (heavy rains fell through May) it was 6 per cent and 3 per cent, respectively, above site 2; but by the end of the month, after active growth had been in progress for nearly a month with no rainfall, it had fallen to 4 per cent below site 2. On August 1, after prolonged heavy rainfall, site 1 again takes the lead, but loses it with the decline in precipitation during the latter part of August and September. These graphs furnish a striking illustration of the power of tree roots to reduce soil moisture. Although the areas occupied by living tree roots had a considerable margin at the beginning of the season, it became drier by the end of June and in September than the other area, in which there were no active tree roots. The 12-inch samples probably show the effect of tree roots better than any other depth, since they represent the level of maximum root activity, and also are below the influence of direct surface evaporation. According to the investigations of Rotmistrov (*22*), the effect of direct evaporation is practically limited to the surface 12 inches of soil. Buckingham (*3*) finds that under arid conditions, such as prevail in the Southwest, the soil automatically protects itself against extreme drying by forming a natural mulch on the surface.

In the 24-inch series, site 1 again seems to have the higher moisture content at the beginning of the season. Unlike the 6-inch and 12-inch series, which show a sharp decline during June, the 24-inch samples rise steadily through this period. This indicates that comparatively little moisture was drawn from the lower soil strata dur-

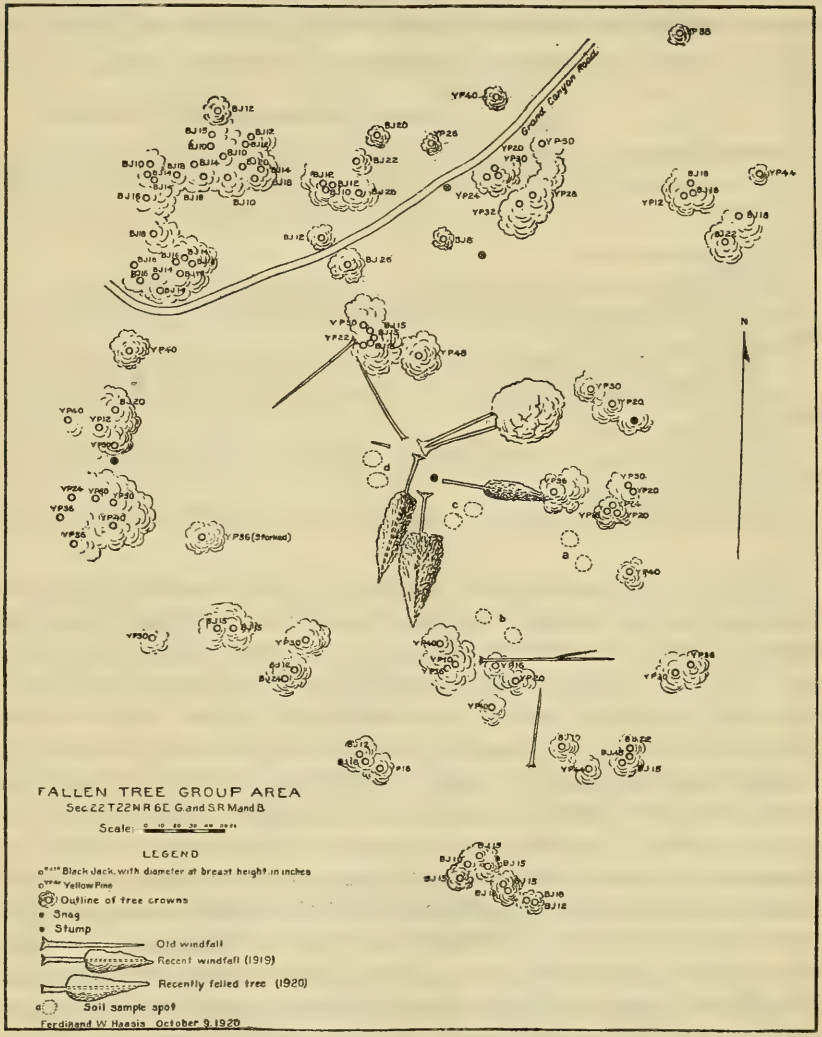


FIG. 10.—Location of soil sampling points, Table 17.

ing the early part of the growing season in 1919. Whether this was due to the unusually heavy rainfall in May, or whether it is a normal condition, is not certain. It is known, however, that roots are most numerous above the 2-foot level, and that the soil warms up slowly below the first foot. By the end of August the effect of root action had become apparent even at a depth of 2 feet, as shown by the

sharp drop on site 1, while site 2 continued to rise until a month later. The rise in both graphs in October is attributed to a slowing-up of plant activity because of cool weather. Nearly all herbaceous vegetation was either mature or was killed by frost early in October.

The above experiment was repeated in 1920 on a similar site about one-fourth mile distant from the first, but in a denser stand. The 1919 experiment was in a lightly cut stand bordered on the south, about 100 yards distant, by a heavier cutting. In 1920 a site was selected in the midst of a virgin stand. A group of five yellow pines 20 to 30 inches in diameter was uprooted the preceding fall by a wet snow, the weight of which caused the trees to fall in different directions, as shown in Figure 10. This created an opening 160 feet wide by 400 feet long, the bases of the fallen trees being a few feet north and east of the center. The herbaceous vegetation was similar to that of the 1919 site, excepting that only a small amount of lupine appeared during the summer. As in 1919, the soil samples were taken well outside the heavily littered and shaded areas. No samples were taken within 10 feet of the branches or trunks of the fallen trees. All things considered, this experiment would be expected to show a sharper contrast between the areas of live tree roots and those of dead tree roots than did the 1919 experiment. Because of greater density of the stand surrounding the opening, the contrast in root activity was probably greater in this experiment than in that of 1919. Subnormal rainfall in 1920 served to accentuate this contrast. Close grazing eliminated to a large extent the effect of herbaceous vegetation, and therefore it is believed that any differences in soil moisture may be attributed mainly to differences in the activity of tree roots. In the 6-inch samples, however, direct evaporation also plays an important part. Since this is least near the standing trees, on account of the partial shade, it tends to minimize the effect due to differences in root activity.

TABLE 17.—*Effect of cutting upon soil moisture, 1920.*

Depth and location.	Wilting coefficient.	Available soil moisture in percentage of dry weight.							
		May 17.	June 4.	June 19.	July 5.	July 14.	Aug. 9.	Sept. 1.	Oct. 6.
Depth 6 inches:									
A. West of experiment station—									
Area of root action (near group of living trees)—									
West	11.6	8.9	5.7	3.2	1.3	0.0	6.8	2.4	−0.5
North	11.6	7.6	9.0	2.9	−0.7	−0.5	6.7	3.2	1.9
No active roots (near group of fallen trees)—									
South	11.5	8.6	10.2	4.5	5.3	0.4	11.4	3.7	4.0
West	10.3	10.7	9.2	6.7	7.4	2.8	11.6	5.0	4.5
Depth 12 inches:									
Near group of living trees—									
West	14.0	9.9	5.3	1.9	4.1	2.3	6.2	2.1	1.6
North	14.0	7.0	5.9	2.1	−0.1	0.3	1.8	−0.2	−0.1
Near group of fallen trees—									
South	11.6	10.8	11.0	8.3	9.6	4.8	10.5	6.5	6.9
West	11.9	11.2	9.9	8.7	8.7	6.2	8.9	6.0	5.1

Table 17 and Figure 11 show a decidedly higher moisture content within the area in which the action of tree roots has been eliminated. These differences are especially significant during the critical period from June 15 to July 15. In the 6-inch samples the contrast is not so striking, on account of direct evaporation, as explained above; but the 12-inch samples are without exception

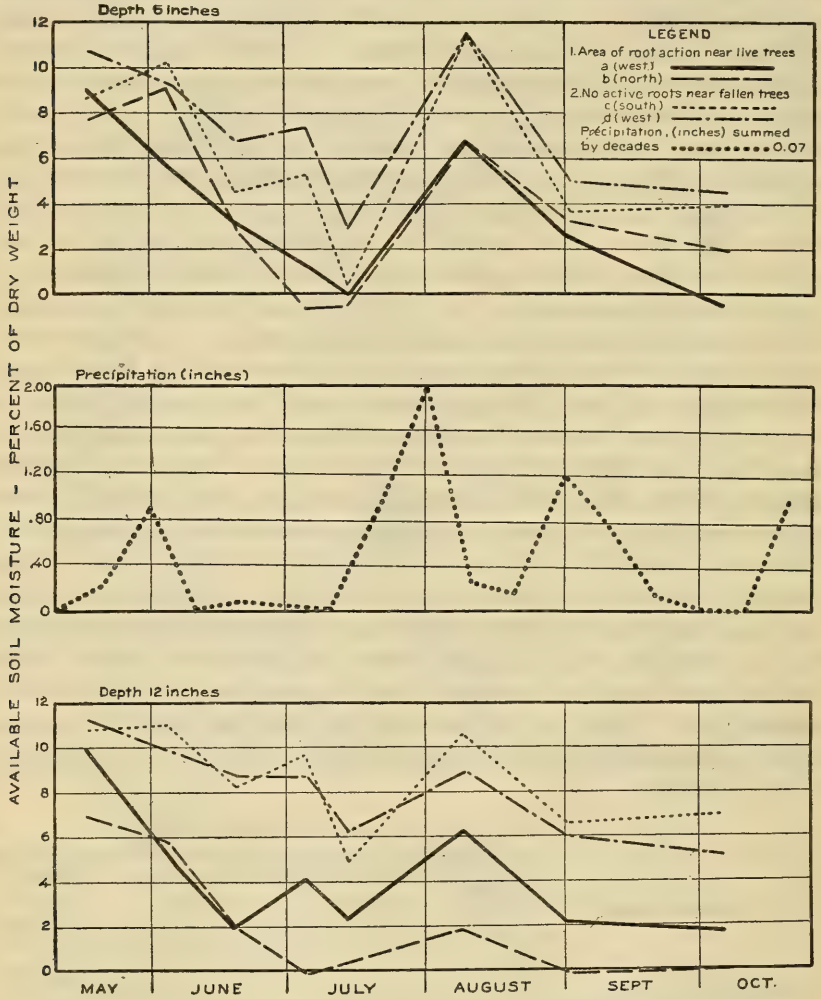


FIG. 11.—Effect of cutting upon soil moisture, 1920.

much higher near the fallen trees. In the area occupied by the live tree roots, the moisture fell to or below the wilting coefficient in four instances during the season at the 6-inch depth, and in three instances at the 12-inch depth, whereas in the area occupied by no live tree roots the lowest point reached even at 6 inches was 0.4 per cent above the wilting point.

F—150923

FIG. 1.—REPRODUCTION IN THE OPENINGS OF A VIRGIN STAND; NONE UNDER OR TO THE NORTH OF THE LARGE GROUPS OF TREES.

F—76632

FIG. 2.—EXCELLENT REPRODUCTION ON THE NORTH SIDE OF A SINGLE CLEAR-BOLED TREE. WHERE THE TREES OCCUR SINGLY OR IN SMALL OPEN GROUPS, RELATIVELY FEW SEEDLINGS ARE SHADED OUT.

F—160237

FIG. 1.—SEEDLINGS ON STUMP PATCHES ARE VERY LARGE AND VIGOROUS, PROVIDED HERBACEOUS VEGETATION IS KEPT DOWN.

The seedling shown in this photograph is 3 years old and measures 5.5 inches to the terminal bud.

F—2-GAP

FIG. 2.—THREE-YEAR-OLD YELLOW PINE SEEDLINGS; THOSE CLASSED AS VERY LARGE OCCUR ALMOST EXCLUSIVELY IN STUMP PATCHES OR IN SLASH WITH NO COMPETING VEGETATION; LARGE SEEDLINGS ARE USUALLY FOUND ON BARE SOIL, SUCH AS OLD ROADS, LOG LANDINGS, AND THE SITES OF BURNED BRUSH PILES; SEEDLINGS OF MEDIUM AND SMALL SIZE PREVAIL ON GRASSY AREAS.

F—89812

FIG. 1.—A TYPICAL FOREST SERVICE CUTTING, SHOWING SCATTERED YELLOW PINE SEED TREES AND GROUPS OF IMMATURE BLACKJACK.

F—43861A

FIG. 2.—SAME CUTTING AFTER 10 YEARS. NUMEROUS SEEDLINGS FROM 3 TO 5 YEARS OLD ARE HIDDEN IN THE GRASS. SAMPLE PLOT 3A.

F—43870A

FIG. 1.—PRIVATE CUTTING. REMAINING TREES DEFECTIVE OR TOO SMALL FOR EFFECTIVE SEED PRODUCTION.

F—161978

FIG. 2.—MATURE STAND OF WESTERN YELLOW PINE, WITH REPRODUCTION IN OPENINGS.

Sheep were excluded following a good seed crop in 1913.

TRANSITION ZONES.

The above test applies to areas either well within the zone of maximum root activity or entirely beyond the reach of tree roots, that is, within a radius of 30 to 40 feet from living trees on one hand and the same distance from the stumps of felled trees on the other. Obviously there are transition zones intermediate between these extremes. In order to secure some idea in regard to the effect of cutting in different conditions of root activity, samples were taken in 1919 at various points in transects extending from groups of freshly cut stumps, across openings, and into groups of living trees. Two such transects were made, one on a light limestone-sandstone soil and another on a heavy clay loam derived from basalt. In both instances from 75 to 80 per cent of the timber had been logged off within a few months or a year previous to the soil sampling. Wilting coefficients were not determined, and therefore the results are expressed in terms of total rather than net available moisture content. In view of this fact, care was exercised to secure samples of apparently uniform texture, especially with reference to clay content. This necessitated omitting a few of the selected sampling points.

TABLE 18.—*Soil moisture in various zones of root activity.*

LIMESTONE-SANDSTONE SOIL, 1919.

Distance of sampling points.		Total soil moisture, per cent.			
		June 13.		June 28–30.	
From trees.	From stumps.	6 inches.	12 inches.	6 inches.	12 inches.
105 feet west	15 feet east	10.1	8.4	7.0	6.2
90 feet west	35 feet east		6.5	4.6	4.9
40 feet west	85 feet east	4.8	4.7	4.3	4.1
20 feet west just outside of crowns	105 feet east	4.9	5.6	3.7	3.2
Under trees	120 feet east	7.0	7.2	3.8	3.9

BASALTIC CLAY LOAM SOIL, 1919.

Distance of sampling points.		Total soil moisture, per cent.	
From trees.	From stumps.	June 14, depth 6 inches.	July 1, depth 6 inches.
55 feet west	60 feet east	19.8	14.2
20 feet west just outside of crowns	90 feet east	17.8	14.6
Under trees		20.7	14.8
20 feet east, just outside of crowns	90 feet west	15.0	11.3
50 feet east	60 feet west	19.7	12.9
80 feet east	30 feet west	21.0	18.0
110 feet east	In group of stumps	22.4	19.7

NOTE.—In both soils the moisture content is higher directly under the trees than at a distance. This is evidently due to shade.

The results which are given in Table 18 corroborate in a rough way those in Tables 16 and 17. They indicate that the influence of tree roots upon soil moisture may extend at least 80 to 90 feet from the trees. In other words, if a group of trees is cut, we may expect an increase in soil moisture in an area extending from 80 to 90 feet or possibly more from the stumps, provided that the roots of living trees are not encountered. If the stand is clean-cut, we may normally expect an appreciable increase in soil moisture over the entire area, save for openings which before the cutting were so large as to be beyond the influence of tree roots. If only a part of the stand is removed, the effect is of course less, though not necessarily in direct proportion to the amount of timber left. It is presumed that if areas from which trees are removed remain unoccupied by trees or by herbaceous vegetation, roots from neighboring trees will reach into these vacant spaces and eventually take possession of the soil.

EFFECT OF CUTTING MODIFIED BY HERBACEOUS VEGETATION.

In the preceding soil-moisture tests, complications due to herbaceous vegetation were to a considerable extent avoided by selecting sites which were closely grazed. That a luxuriant growth of grass and other herbs extracts large amounts of moisture from the soil is obvious. It also checks evaporation from the surface layers, but the amount conserved in this way is far less than the amount transpired through the foliage. It is conceivable, therefore, that the entrance of herbaceous vegetation after cutting may offset the saving of soil moisture brought about by removing the trees. This actually happens in a great many instances, and there is always a tendency in this direction. Cutting stimulates the growth of the herbaceous cover which has been held in check by the shade and root competition of the trees. The total amount of vegetation of all kinds which can exist on a given site in this region is determined by the amount of moisture available at critical times. Whenever a surplus of soil moisture is created by removing a considerable proportion of the trees, as in logging, the remaining plants, both trees and herbs, respond by increased growth, and those which reproduce most readily increase in numbers until the limit of moisture supply is again reached.

Changes in ground cover are most active on the areas released from the domination of the trees which are cut, and particularly the spots on which the herbaceous vegetation has been largely suppressed by the trees. The conditions prevailing in these situations or stump patches have been described under "Herbaceous vegetation." Immediately after cutting the stump patches show a high excess of soil moisture as compared with areas of established vegetation. But

the weedlike plants which are usually present in a subdued form under the trees spring up quickly after the trees are removed and within five years, if their growth is not interfered with, they develop a cover which is much denser and more luxuriant than normal grass areas. When this stage is reached the soil moisture becomes more completely exhausted in stump patches than elsewhere. If pine seedlings can secure a foothold before the herbaceous growth becomes too dense, or if the latter is held in check by proper grazing or other means, they develop much more vigorously in the stump patches than in other situations (Pl. XII); but if from lack of seed or other causes germination is deferred several years after cutting and the herbaceous plants are not kept down, the pine seedlings which do start find themselves in a veritable jungle of vines and other leafy herbage which not only robs the seedlings of moisture but in many cases completely covers and chokes them out. The stump patches, because of the palatability of their forage plants, are very closely cropped where stock is permitted to graze. This gives the pine seedlings a chance, provided that they, too, are not devoured, as is the case on improperly grazed sheep range.

A comparison of various situations with respect to the progress of the large stand of seedlings which originated in 1919 brings out the following relations. On sheep range the stump patches are very closely cropped, so that scarcely a pine seedling remains alive, and those living are usually injured; but in adjoining bunch-grass areas considerable numbers of seedlings have escaped injury because of the protection of the grass, which is but lightly grazed by sheep. On stump patches from which all grazing has been excluded for 10 years, almost every seedling has been choked out by the luxuriant herbaceous cover. On areas which were heavily grazed by cattle and sheep up to 1919 and subsequently excluded to sheep, pine seedlings in stump patches are from two to three times as large as those of the same age outside the stump patches. The conclusions to be drawn from the above relationships are unmistakable. Disregarding the damage by sheep grazing, which will be more fully discussed under "Grazing," this fact stands out so plainly that it can not be overlooked: *Western yellow pine seedlings grow best where they are unhampered by the root competition and shade of older trees or herbaceous vegetation.* Organic matter added to the soil by the decay of leaf litter and roots and the aeration provided by large roots are undoubtedly important contributory factors in the vigorous growth of seedlings in stump patches. The forest should be so managed that these conditions as well as the moisture made available when mature trees are cut may be utilized by pine seedlings rather than by herbaceous plants.

RESULTS ON CUT-OVER LANDS.

1909–1918.

For many years an effort has been maintained to determine the effects of different methods and degrees of cutting upon reproduction by direct comparison of results as shown by progress in restocking. Cut-over areas on the Coconino and Tusayan National Forests do not, as a rule, lend themselves well to such studies, for the reason that the operation of natural factors is obscured by the damage due to sheep grazing, with the result that reproduction during the past 10 or 15 years has failed uniformly. This difficulty has been met on local areas by fencing. Three areas were fenced in 1908, six in 1910–11, and two in 1919. In addition, a considerable number of privately owned pastures grazed only by cattle and horses are scattered through the forest.

As shown by Tables 1 to 4 and the accompanying discussion under "Studies on permanent sample plots," reproduction even on areas protected against sheep progressed with extreme slowness during the 10 years prior to 1919. Nevertheless, two of these areas, 3A and 3B, cut by the group-selection method and representative of the bunchgrass type in a locality where reproduction is generally very poor, show at the end of 11 years an average of 222 seedlings per acre from 4 to 11 years of age. Areas on which reproduction progresses at this rate should be fairly well stocked at the end of 20 years, assuming for complete stocking a minimum of 200 seedlings per acre 10 or more years of age.[14] Moreover, it is almost certain, in the light of recent investigations, that with proper control of ground cover the rate indicated above will be exceeded. It is also to be considered that the large seedling crop of 1919, of which about 7,000 per acre remained on sample plots 3A and 3B at the end of three years, has not been taken into account.

The above results are equaled or excelled on dozens of fenced areas in different parts of the forest. In two instances complete stocking of over 1,000 seedlings per acre, now over a foot in height, was

[14] The determination of what constitutes complete reproduction of western yellow pine in this region has always been a perplexing problem. Stands of 1,000 or more even-aged seedlings per acre would be desirable, but observations indicate that in many instances we will have to be content with less. Denser stocking will be obtained only when there happens to be an unusually favorable combination of seed and rainfall. Such occurrences are so rare and uncertain that they can not be depended upon. It is believed that out of a stand of 200 10-year seedlings per acre there will be sufficient survival to give a stocking at least as good as the original stand. It must be expected, however, that on all but the most favorable sites fail spots from 50 to 100 feet in diameter, due to heavy soil, dense grass, or other adverse conditions, will be of common occurrence. Such openings do not represent a total waste, because they are permeated by the roots of surrounding trees as much as 100 feet distant. There is reason to believe that the present group formation will persist in future stands unless we resort to plantings or other artificial aids to natural reproduction.

secured from the 1913 seed crop alone. Extensive observations by the writer and others warrant the statement that wherever an area well provided with seed trees has been adequately protected against sheep grazing and fire for 10 years or more reproduction is making substantial progress. The average period for complete restocking has been placed at 20 years. On adverse sites or under unfavorable conditions with respect to coincidence of seed crops and rainfall, the period may be longer, whereas under favorable conditions it may be greatly shortened.

Results during the past 10 years show that as far as cutting alone is concerned the method practiced by the Forest Service is reasonably sure of success. The persistent failure of cut-over lands to restock has been due not to the method of cutting but to the disregard of other silvicultural requirements, principally control of ground cover and protection against sheep. This, however, does not prove that the present method of cutting can not be improved upon. Can better results be secured by leaving more trees, or are we leaving more trees than necessary? The evidence obtainable from old cuttings is conflicting, due to varying conditions of site, seed supply, and grazing. Studies of the large stand of seedlings which originated in 1919 throw additional light on the subject.

Table 19 gives the results of seedling counts in cut-over and virgin stands in which the number of possible seed trees ranges from 2 to 20 per acre and where the distribuion varies from widely scattered single trees to the other extreme, in which nearly all occur in large groups. Pronounced variations in seed crop, soil, and ground cover have made it necessary to classify the areas into several groups. On account of the abundant rainfall in 1919, which created almost ideal conditions for germination, variation in seed supply was by far the greatest factor during the first season. In the second and third seasons, however, the influence of site came into play in determining survival.

Group I covers the cut-over region in the bunch-grass type, in which sample plots 3A and 3B are located. An unusually heavy seed crop prevailed over this entire region in 1918. Even small trees down to 12 inches in diameter, if growing in the open, were loaded with cones. For this reason the heavy cuttings on which only a few small trees are left show up to much better advantage than would be the case under normal conditions. It is at once apparent that the number of seedlings is at least in a general way related to the number of seed trees. The "timber rights" section, with its four trees per acre (very few above 15 inches diameter breast high) is so far down the scale as to leave no doubt as to the

TABLE 19.—*Reproduction in relation to method of cutting and number of seed trees.*

Area and location.	Area (acres).	Character of cutting.	Year cut.	Crown area, per cent total.	Seed crop, 1918.	Trees left after cutting, per acre, 1919.							
						Volume (ft. b. m.).	Number.[1]		Number by d. b. h. classes.				
							Y. P.	B. J.	12 to 20 inches.	21 to 30 inches.	Over 30 inches.	Over 20 inches.	Over 11 inches.
I. Northwest of Fort Valley, 5 to 10 miles:													
1. Sample plot 3, open range	456	Forest Service, group selection	1909	.....	Heavy	4,400	1.4	10.7	7.7	3.6	0.7	4.4	12.1
2. Sample plot 3A, fenced	12	do	1909	11.0	do	5,000	1.5	13.5	9.8	4.2	0.9	5.2	15.0
3. Sample plot 3B, fenced	12	do	1909	18.3	do	6,800	.....	23.2	15.3	7.6	0.1	7.8	23.2
4. "Timber rights" land, open range.[2]	.....	Almost clean cut	1912	.....	do	400	1.0	3.0	4.0	.....	.....	.....	4.0
5. Virgin stand [2, 3]	.....	Forest Service, group selection	1920	.....	do	10,000	.....	.....	.....	.....	.....	10.0	20.0
II. Around Fort Valley Experiment Station:													
6. Sample plot 1, fenced	243	Old private cutting	1894	.....	do	3,500	3.4	6.7	6.4	3.2	0.4	3.7	10.1
7. Sample plot 1A, fenced	6.8	do	1894	7.4	do	3,900	3.7	11.9	11.0	4.4	0.1	4.6	15.6
8. Sample plot 1B, fenced	10	do	1894	4.9	do	4,200	5.0	3.1	4.1	2.9	1.1	4.0	8.1
9. Old cutting, sec. 21, open range.[2]	640	do	About 1896	.....	do	1,500	2.0	5.0	.....	.....	.....	2.0	7.0
10. Virgin stand (sec. 22)	120	Few trees removed	.....	.....	do	11,600	8.5	10.2	8.0	8.3	2.3	10.6	18.7
III. East of Fort Valley Experiment Station, 2 miles:													
11. Sample plot 2B, fenced	.....	Old private cutting	1895	.....	Good	6,300	7.1	9.0	8.9	5.5	1.6	7.1	16.1
12. Virgin stand [2]	.....	Few trees removed	.....	.....	do	9,000	.....	.....	.....	.....	.....	8.0	15.0
IV. Cinder region, northeast of Flagstaff:													
13. Sample plot 4A, open range	8	Forest Service, group selection	1909	11.0	Very light	3,700	1.9	13.8	10.7	4.5	0.5	5.0	15.7
14. Sample plot 4B, open range	8	do	1909	12.5	do	4,200	1.4	14.7	10.5	5.2	0.3	5.6	16.1
V. South of Maine, 15 miles:													
15. "Timber rights" land, open range.[2]	320	Almost clean cut	1917	.....	Good	.....	.....	.....	.....	.....	.....	1.0	4.0
16. Virgin stand, open range[3]	160	No cutting	.....	.....	do	6,000	.....	.....	.....	.....	.....	8.0	17.0
VI. Southeast of Flagstaff, 8 miles:													
17. Greenlaw sale area, open range.[2]	.....	Forest Service, group selection	1916	.....	do	2,000	.....	.....	.....	.....	.....	3.0	10.0
VII. Sample plot 5, south of Flagstaff, 20 miles:[4]													
18. Plots A and D, fenced	20.6	Forest Service, group selection	1913	[5]11.8	do	3,500	.....	.....	10.4	3.4	0.3	3.8	14.2
19. Plots B, C, and E, fenced	16.9	Forest Service, scattered seed tree.	1913	5.2	do	2,600	.....	.....	0.8	2.1	0.5	2.7	3.6
20. Plots B, C, and E, fenced	14.6	Forest Service, shelter wood	1913	17.3	do	6,900	.....	.....	13.1	6.1	0.8	7.0	20.1

TABLE 19.—*Reproduction in relation to method of cutting and number of seed trees*—Continued.

Area and location.	Soil and herbaceous vegetation.	Grazing.[6]	Area of plots (sq. ft.).	Number of 1919 seedlings per acre.					
				August, 1919.	May–June, 1920.	August. 1920.	November, 1920.	June, 1921.	September, 1921.
I. Northwest of Fort Valley, 5 to 10 miles:									
1. Sample plot 3, open range	Basaltic clay loam; bunch grass very heavy.	C, H, S.	900	75,000	51,000	14,300	9,100	6,800	5,000
2. Sample plot 3A, fenced		None	400	90,000	43,000	15,100	12,200	12,100	10,200
3. Sample plot 3B, fenced		do	400	61,000	37,000	8,400	8,175	6,900	4,900
4. "Timber rights" land, open range [2]		C, H, S.	400	3,000	1,650	.....	320	.....	.....
5. Virgin stand [2, 3]		C, H, S.	800	145,000	50,000	27,500	12,200	7,900	7,400
II. Around Fort Valley Experiment Station:									
6. Sample plot 1, fenced	Basaltic clay loam; bunch grass and weeds.	None or C, H.	800	36,000	22,000	3,500	3,500	1,360	925
7. Sample plot 1A, fenced		C, H	400	.....	31,000	11,200	10,600	9,900	6,900
8. Sample plot 1B, fenced		.....	400	69,000	37,000	13,900	13,400	10,800	7,100
9. Old cutting, sec. 21, open range [2]		C, H, S.	960	.....	6,700	.....	2,200	.....	.....
10. Virgin stand (sec. 22)		C, H, S[7].	950	141,000	69,000	27,500	23,900	18,700	14,200
III. East of Fort Valley Experiment Station, 2 miles:									
11. Sample plot 2B, fenced	Gravelly soil; grass and weeds	None	300	.....	6,700	1,305	1,305	1,160	1,015
12. Virgin stand [2]		C, H, S.	300	30,000	21,000	10,900	8,700	8,700	7,400
IV. Cinder region, northeast of Flagstaff:									
13. Same plot 4A, open range	Cinders on surface; bunch grass in patches.	C, H, S.	400	320	.....	.....	.....	.....	109
14. Sample plot 4B, open range		C, H, S.	400	1,850	.....	.....	.....	.....	437
V. South of Maine, 15 miles:									
15. "Timber rights" land, open range [2]	Limestone	C, H, S.	.....	700	.....	.....	.....	.....	.....
16 Virgin stand, open range [2]		C, H, S.	.....	26,000	.....	.....	.....	.....	.....
VI. Southeast of Flagstaff, 8 miles:									
17. Greenlaw sale area, open range [2]	do	C, H, S.	200	9,000	.....	.....	.....	.....	.....
VII. Sample plot 5, south of Flagstaff, 20 miles: [4]									
18. Plots A and D, fenced	Basaltic clay loam, shallow; grass and weeds, variable.	H	2,480	.....	3,940	.....	Survival about 60 per cent.	1,005	730
19. Plots B, C, and E, fenced		H	6,150	.....	2,825	.....		1,005	970
20. Plots B, C, and E, fenced		H	3,440	.....	7,875	.....		3,400	2,990

[1] Y. P=Yellow pine; B. J.=Blackjack.
[2] Stand estimated.
[3] Cut the year following germination.
[4] Each group of plots represents area of 120 to 160 acres.
[5] Including gambel oak, crown areas of the three cutting divisions are 17.1, 11.3, and 20.2 per cent, respectively.
[6] C, H, S=Cattle, horses, and sheep, respectively.
[7] Sheep grazing light.

inadequacy of its seed supply.[15] The virgin stand, with a total of 20 trees per acre (estimated), about half of which are over 20 inches, heads the list in number of seedlings. Plot 3B, however, with its 23 trees per acre over 11 inches, has a third less seedlings than 3A with only 15 trees, and about the same number as plot 3 with only 12 trees. This discrepancy is at least partially explained by the fact that plot 3B has a very large proportion of small trees (below 21 inches) and that they occur in unusually large groups. It is evident that we must consider size, crown development, and distribution as well as total number of trees. Considering only the trees above 20 inches in diameter, plot 3B still has a good margin over plots 3 and 3A, but it has a smaller number of large, free-standing trees than the other two plots. This relation is illustrated by the number of yellow pines. Plot 3B has no yellow pines, whereas plots 3 and 3A have 1.4 and 1.5 per acre, respectively. As explained in the chapter on seed supply, yellow pines as a class are better seed trees than blackjacks, because of their greater size and better crown development and because a yellow pine is rarely left unless it is a good seed tree, whereas blackjacks are left indiscriminately unless they are plainly diseased or defective.

In comparing the areas in Group I, the number of seedlings needed, as well as the number present, should be considered. If an area has twice as many seedlings as are needed for full stocking, there is a possibility that it has more seed trees than are necessary. It is difficult to fix a definite standard as to the minimum requirement for full stocking, because of uncertainty as to survival. Records of a number of seedling stands indicate that 10 per cent is a conservative figure for survival between the second and the tenth year. Assuming a minimum of 200 ten-year-olds per acre as full stocking, all of the areas in Group V, excepting the "timber rights" sections, may be expected to show a surplus at the end of the 10 years. This indicates that even the most lightly stocked area, plot 3, has more seed trees than are absolutely needed. Before ac-

[15]An extensive survey of this region by M. W. Westveld in June and July, 1920, covering 65 sections of alternating Forest Service and "timber rights" cuttings, gave an average of 6,325 1919 seedlings per acre for the former and 3,113 for the latter. On many of the "timber rights" sections the stand ran as high as 10 trees over 12 inches per acre. On such areas seedlings were almost as numerous as on Forest Service cuttings. Considerable areas, however, had as few as 2 trees per acre, and here seedlings were almost entirely absent. The figures for Forest Service cuttings average considerably below those on sample plots 3, 3A, and 3B. This is due partly to fewer seed trees and partly to the fact that on a considerable portion of the area covered by Westveld the seed crop was lighter than in the vicinity of plots 3, 3A, and 3B. Assuming the same rate of mortality on the sections examined by Westveld as on the sample plots, it seems evident that even the Forest Service cuttings will scarcely have sufficient survival for complete stocking, whereas the "timber rights" sections will certainly fall below the standard. The entire area covered by Westveld's survey, as well as sample plot 3, has been grazed by sheep, which have destroyed over 25 per cent of the 1919 seedling crop. Sheep were excluded from the greater portion of this region in 1921.

cepting this conclusion, however, it must be considered that we are dealing with a stand of seedlings which has originated under almost ideal conditions with respect to both seed supply and moisture, and that therefore the figures on number of seedlings per acre must be greatly discounted in order to be applicable to average conditions. Moreover, 200 per acre at 10 years of age has been assumed as a minimum standard; 1,000 per acre would be very much better. It is well before proceeding further to consider results on other areas.

Group II also lies in the region of the heavy 1918 seed crop and, except for lighter grass cover, it is comparable to Group I. The virgin forest in both groups contains very dense stands of 1919 seedlings. All the cut-over areas in Group II, however, were logged under private management, which means that most of the larger trees (yellow pine) have poor crowns. This condition is strikingly prevalent on section 21. Another characteristic of these cut-over areas is the uneven distribution of trees. It is common to find openings 4 to 5 acres in extent bearing only two or three old spike-topped trees. On plots 1A and 1B these conditions have been avoided to a great extent. Results on these plots compare favorably with those on the sample plots in Group I. The other two cut-over areas, however, fall far below sample plot 1A and 1B, probably on account of a larger proportion of defective trees and poorer distribution. The poor survival on plot 1 has remained unexplained until recently. Examinations in September, 1921, show that the seedling plots are almost invariably situated in spots which are unfavorable to survival. Considerable numbers of saplings occur in irregular groups over most of the area. The seedling plots are often near enough to these saplings to feel the influence of their roots. Many of the seedling plots occur on clay flats, where reproduction is generally poor. The very fact that the plots selected for seedling counts are in spots which have not restocked during the past 20 years, although seedlings have come in all around them, indicates that they are on unfavorable sites. Section 21 sustained considerable damage from sheep grazing during the summer of 1920.

Group III, in comparison with Groups I and II, shows clearly the effect of seed supply. The areas in Group III occupy a better site than the others, but the seed crop was much lighter. Here, as in Groups I and II, the virgin stand shows a greater abundance of seedlings than the cut-over areas.

Group IV (sample plots 4A and 4B) furnishes a striking example of the interdependence of rainfall and seed supply. Because of the presence of a deep surface layer of cinders, pine seed germinates poorly in seasons of average rainfall. Two fairly good seed crops

which are known to have occurred on these plots since 1909 have yielded but few seedlings, because they were followed by deficient rainfall. In 1919 copious rains throughout the summer would have insured reproduction had a good supply of seed been present. Through failure of the seed crop in this locality in 1918, moisture conditions such as are not likely to occur again in 20 years were rendered futile. Without an abundance of rain in July and August, reproduction will fail on these plots, regardless of the number of seed trees. A large number of seed trees should be left, however, so that whenever a good seed crop and required moisture conditions do coincide, there will be sufficient seed to secure complete restocking.

Group V again proves the inadequacy of a small number of seed trees such as are left on "timber rights" sections.

Group VII indicates what may be expected on present-day Forest Service cuttings with abundant rainfall but only an average "good" seed crop. Had the seed crop been as heavy on this area as in Groups I and II, it is safe to say that the number of seedlings would have been increased threefold. Since this group involves three methods of cutting, it will be discussed in greater detail under the next caption.

Comparison of methods of cutting.—Group VII provides a comparison between silvicultural systems without going to such extremes as are encountered in comparing Forest Service cuttings with "timber rights" areas. In other words, the test in Group VII is confined to methods which have silvicultural possibilities. An area was cut according to each of the following methods:

(1) Group selection.—This method, with minor modifications, has been the standard of the Forest Service in the Southwestern district for 15 years. It may be briefly characterized as a selection system in which even-age tree groups are treated as individual trees. Mature and overmature groups (yellow pine) are removed unless needed for seed production or shelter; immature groups (blackjack and intermediate trees) are left, unless they are diseased or defective or unless improvement cuttings can be advantageously made. It is desirable to preserve the natural groupings, because the disintegration of groups increases windfall. Trees which have grown in an isolated position are most desirable to leave, but usually they are too few. The application of this system is outlined in detail at the end of this chapter. In present practice, from 75 to 80 per cent of the stand is removed, leaving 1,500 to 2,000 feet b. m. in trees over 11 inches diameter breast high. These cuttings are considerably heavier than those of 10 years ago, when the amount left ran from 2,500 to 3,500 feet b. m.

(2) Scattered seed-tree method.—Scattered trees were left at the rate of from 3 to 4 per acre. Aside from the trees left for seed,

everything down to 11 inches diameter breast high was felled. The area was not left as open as might be expected, because of the presence of groups of young unmerchantable pine and of Gambel oak. All of the reserved trees were selected with special reference to capacity for seed production. Windfirmness, good crown development, and general vigor were the primary qualifications. As far as possible they were distributed uniformly and singly, although occasionally 2 or even 3 were left in a group. Table 19 shows that 75 per cent of the seed trees on this area are over 20 inches in diameter.

(3) Shelterwood.—As this cutting was actually carried out, it does not conform to the specifications of the shelterwood system. It differs from the group-selection method only in leaving more mature trees. The volume after cutting, as shown by Table 19, was 6,600 feet b. m., or three times as great as on the group-selection area. Since this excess volume is made up almost entirely of large trees, and since yellow pine stands are very open to begin with, the appearance of the two stands after cutting does not suggest any radical difference in silvicultural practice.

The three cutting areas are contiguous and similar in topography, soil, and vegetation. The group selection and scattered seed-tree divisions each contain 160 acres, and the shelterwood division 112 acres. A shallow, stony, clay soil, derived from basalt, predominates. Three rather distinct qualities of site are recognized: (1) flats or valleys with alluvial soil 18 to 24 inches deep, practically free of stones, ground cover mainly *Festuca arizonica;* (2) lower slopes, soil 12 to 18 inches deep, more stony than (1), ground cover mainly bunch grasses (*Muhlenbergia montana* and *Festuca arizonica*); and (3) upper slopes and mesas with soil seldom exceeding 6 inches deep, surface very stony, ground cover mainly black sporobolus (*Sporobolus interruptus*).

At the time these areas were established, in 1913, seedlings from 10 to 15 years old, mostly damaged by sheep, occurred in scattered clumps, mainly on site 2. There were also a considerable number of 2-year-old seedlings, nearly all of which died in the succeeding 2 years, partly as a result of injury by sheep.

Seven plots of from 2 to 4 acres each were selected within each cutting division for studying reproduction and other problems. They are distributed so as to represent all the site qualities. Each plot was mapped as illustrated by Figure 1. During the summer of 1919 two sheep-proof fences were built so as to include three reproduction plots within each cutting area.

Considering the representative character of the sample plots within the various cutting divisions and the relatively large area covered by seedling counts, we should expect the initial number of seedlings to be in some measure proportional to the number of

seed trees. Analysis of the data shows no such relationship when we consider all the trees above 11 inches in diameter, but a surprisingly close relationship when only the trees above 20 inches are taken. Dividing the number of seedlings at the first count, in June, 1920, by the number of trees over 20 inches in diameter, the quotients for the group-selection, scattered seed-tree, and shelterwood methods are 1,040, 1,050, and 1,120, respectively. In other words, there were roughly 1,100 seedlings for each tree. In view of the fact that these counts were made 9 months after germination, and taking into account the great difference in distribution of diameter classes on the three areas, the constancy of this ratio must be regarded as partly accidental, but that there is a definite relationship can scarcely be doubted. The obvious conclusion to be drawn from these observations is that the smaller trees, those between 11 and approximately 20 inches in diameter,[16] are of relatively little importance in reproduction. This deduction is substantiated in a broad way by the findings under "Seed supply," which show that no less than 5 blackjacks of the average run above 11 inches are required to produce the same quantity of seed as a single free-standing yellow pine of the type usually selected for seed production. On the scattered seed-tree area, 75 per cent of the trees are over 20 inches in diameter, whereas on the group-selection area only 30 per cent fall in this class. It is not surprising, therefore, that the scattered seed-tree area with a total of only 3.6 trees per acre should have nearly three-fourths as many seedlings as the group-selection area with its 14.2 trees per acre. Similarly, the shelterwood cutting, which in June, 1920, had almost twice as many seedlings as the group-selection cutting, evidently owed its superiority, not so much to the 6 additional trees per acre in the 12 to 20 inch group, as to the additional 3.2 trees per acre in the group above 20 inches, and particularly to those above 25 inches.

The real test of the three methods with respect to reproduction comes in survival. Unfortunately the seedling counts on these plots have not been made so frequently and regularly as on the plots nearer the experiment station. Nevertheless, the records probably show the trend of mortality with a fair degree of accuracy. From July 1, 1920, to June 15, 1921, the percentage of survival on the various cutting divisions was as follows: Group selection 26, scattered seed tree 35, shelter wood 43. From June 15, 1921, to September 10 of the same year, the percentages were 73, 97, and 88, respectively. The group-selection area is lowest in both periods. The reasons for this are not plain. More frequent examinations on plots near the experi-

[16] It has not been definitely determined where the lower diameter limit of effective seed production lies. No doubt this varies with a number of factors. Sufficient information is available, however, to warrant the adoption of 20 inches as a rough average figure.

ment station show that after the first winter the greatest losses are due to drought in the latter half of June and the first half of July. Shading does not enter, because all excessively shaded plots have been eliminated from these records. Comparing the group-selection and the scattered seed-tree methods, the consistent superiority of the latter might be attributed to the elimination of root competition due to heavier cutting. But this theory is controverted by the shelterwood area, which during the first period showed the highest survival of all. Again, if we attribute the high survival in the shelterwood cutting during the first period to protection, we must account for the fact that survival in the scattered seed-tree cutting exceeds that of the group selection, and during the second period even surpasses the shelter wood.

Further inquiry into the development of seedlings and the character of sites throws additional light on the problem. In the examinations of September, 1921, all 1919 seedlings were classified as to relative size and vigor. Unusually large and thrifty seedlings were classed as "very large." They are generally over 4 inches in height, measured to the terminal bud, with proportional thickness of stem and length of foliage. Somewhat smaller but still vigorous looking specimens were classed as "large." Those which were of only mediocre development, usually not over 2 inches high, were classed as "medium"; and the very smallest were classed as "small." (Pl. XII, Fig. 2.) The results of this classification are shown in Table 20.

TABLE 20.—*Effect of different methods of cutting on size of seedlings.*

Method of cutting.	Basis, number of seedlings.	Per cent.			
		Very large.	Large.	Medium.	Small.
Group selection	48	6	34	38	22
Scattered seed tree	139	20	23	40	17
Shelterwood	301	1	8	53	38

A glance at the above table shows that the shelterwood method ranks far below the other two with respect to size of seedlings, and that the scattered seed-tree method ranks highest in percentage of very large seedlings. These extraordinary specimens occur almost exclusively on stump patches. Stump patches occupy the greatest proportion of area in the scattered seed-tree division and the least in the shelterwood. This fact explains why the scattered seed-tree method leads in both survival and rate of growth. That the group-selection method should excel the shelterwood method with respect to size of seedlings, is obvious, but why it should lag behind in

percentage of survival is not clear. Possibly there are differences in quality of site which have not been taken into account. Although it is too early to predict the final outcome, it is worth while to point out what seems to be the general bearing of developments up to the present time.

The scattered seed-tree method has already outstripped the group selection method in both survival and development of seedlings, and present indications are that it will maintain or even increase this lead. The shelterwood method has a wide margin over the other two methods in point of numbers, but it is distinctly below them with respect to the size and vigor of seedlings now on the ground. Future examinations will probably continue to show most seedlings per acre on the shelterwood area, but they will be smaller and less uniformly distributed than on the other two areas. It is by no means certain that, all things considered, the shelterwood method will not stand at the bottom of the scale two or three years hence.

In deciding which method of cutting should be practiced, the requirements for natural reproduction must be harmonized with existing natural and economic conditions, in so far as the latter are incapable of modification. In the first place, the western yellow pine forests in the Southwest are made up of several age-classes. It is doubtful whether it will ever be practical or desirable to change this arrangement, or at least we can not look toward such a change within the next 50 years. When a stand is logged, there are usually two or more distinct age classes which are either too small to be merchantable or are growing so rapidly that it would be poor business to cut them. Such trees, excluding undesirable individuals, should be left, even though they may be detrimental to reproduction in their immediate vicinity. Another circumstance which must be taken into account is the expense of logging. It is obvious that cuttings, however desirable silviculturally, can not be executed unless the amount of material removed is sufficient to warrant the cost of transportation systems and other more or less fixed investments. With these conditions in mind, we are in a position to decide which of the three methods of cutting, the group selection, the scattered seed-tree, or the shelterwood method, is best adapted to attain the aims of forest management.

The shelterwood method has little to commend it under the conditions which must be met in present-day practice. In order to realize the benefits of the plentiful seed supply and shelter to young seedlings, which are the primary advantages of the method, the mature trees should be removed within three years after the appearance of the main seedling crop. This can rarely be done on account of logging conditions. If the mature trees are not removed at the

proper time, all of the seedlings in their near proximity will be killed or retarded in growth by shade and root competition. Granting that a removal felling may be possible under special conditions, the fact remains that nothing has been gained by the first cutting, because in such open stands as our western yellow pine the removal of a few overmature trees would have little effect in promoting seedling establishment. In fact, if the shelterwood principle is applied at all, germination should be secured under the virgin stand, and within three years the mature and overmature trees should be removed in one operation. If, as would inevitably be the case if this method of cutting were adopted in general practice, the removal fellings are omitted or deferred, we would have returned to the group-selection method, differing from the standard practice only in leaving a larger number of mature trees. Such cuttings would undoubtedly restock more promptly than the standard group-selection cutting as far as the larger openings are concerned, but the actual proportion of area restocked would be less, since few seedlings would survive near the old trees. Against any benefits in the way of reproduction, which are at best doubtful, must be weighed the cost in loss of increment, additional logging costs, and the deterioration of from 2,000 to 3,000 feet b. m. of merchantable timber above the amount left in the standard group-selection method. The shelterwood system was included in this experiment less with the idea that it would ever be adopted in silvicultural practice than with the idea of providing a contrast with other systems. Most of the difficulties which have been pointed out were anticipated. It has been demonstrated that the initial establishment of seedlings is favored by increasing the number of large seed trees, which is one of the principal points on which information was sought. An important point on which stress was laid at the beginning of the experiment was the value of a shelter wood in protecting young seedlings and thus favoring survival. The evidence here obtained shows that the beneficial effects attributed to the shelter of old trees were exaggerated, while associated detrimental effects were underrated. Present indications are that, on the whole, the advantages of the shelterwood method are outweighed by its disadvantages.

In the scattered seed-tree method the outstanding advantages are economy in logging and the creation of favorable conditions for the growth of seedlings. A disadvantage which was anticipated at the beginning of the experiment, but which has not materialized, is injury to seedlings through lack of sufficient shelter. On the contrary, present indications are that the removal of trees in excess of requirements for seed reproduction is ordinarily a distinct aid to reproduction. Although in this experiment the method was handicapped by too small a number of seed trees, the results obtained

point to the desirability of relatively few (four or five) good seed trees rather than a large number of poor or mediocre ones, and they confirm the conclusion announced under "Seed supply" that the large groups of small blackjacks prevalent in most stands are entirely inadequate for reseeding cutover areas. The one great disadvantage of the method is that it removes the young, rapidly growing trees which should constitute the future growing stock. So vital is this fault that it bars the method from further consideration, notwithstanding the fact that it appears to have the greatest possibilities in the way of reproduction.

The group-selection method in a large measure takes advantage of the good and eliminates the bad features of the other two methods. In short, it promises to secure reproduction without disregarding other aims of silviculture. It permits the removal of enough timber to warrant logging operations without sacrificing the forest capital. It aims to avoid excessive losses from deterioration of mature timber, but at the same time to leave enough seed trees in the large diameters to insure reasonably prompt reproduction. It does not free the seedlings from the root competition and shade of older trees in the same degree as the scattered seed-tree method, but it goes considerably further in this direction than does the shelterwood method. Unless it is decided to convert the forests into even-aged stands, which is not contemplated in the near future, a certain amount of suppression of seedlings by immature trees must be accepted. Considering all the conditions imposed by the character and composition of our virgin stands and by economic conditions, the group-selection method comes nearest to meeting the silvicultural requirements of western yellow pine in this region at the present time.

Results on the various sample areas cut according to the group selection method indicate that reasonably good reproduction may be expected in about 20 years. Other things being equal, the period will vary, within certain limits, with the amount of seed available. The fact that the 1918 seed crop alone promises to accomplish the task which would ordinarily require three or four seed crops does not warrant the assumption that we have a margin which may be taken up by reducing the number of seed trees. Such a coincidence of seed supply and rainfall as occurred in 1919 is of too rare and uncertain occurrence to be relied upon in a safe plan of management. On the other hand, provision should be made, by leaving sufficient seed trees, for taking full advantage of such fortunate circumstances when they do occur. This might be used as a criterion as to the minimum number of seed trees required. Applying this standard, the group selection cutting in Group VII barely meets the requirements. The fact that the seed crop in this locality was only what

might be classed as an average "good" crop, however, renders the results reasonably conservative. This area has 3.8 seed trees over 20 inches in diameter per acre. Fewer seed trees would mean fewer seedlings at the present stage, which would clearly not be desirable. We may say then, in answer to the question, "How many seed trees per acre are required?" that for average stands we should count on leaving at least four trees over 20 inches diameter breast high. This is an average figure which calls for variation with the character of the site and stand. As will be explained in the discussion of marking practice, more trees will be needed on adverse sites. If the trees are large, running well above 25 inches in diameter, and of good crown development, the number may be reduced to 3 per acre. On the other hand, if the trees are mostly small (below 25 inches) and of mediocre crown development, as is likely to be the case if they occur in large groups, more than 4 may be needed.

Having established as a minimum the requirement of four seed trees per acre for average sites under the group selection method, we may again refer to the question raised in the discussion of Group I, as to whether areas such as sample plots 3A and 3B are not provided with more seed trees than are really necessary. Plot 3A has 5.2 and plot 3B 7.8 trees over 20 inches in diameter per acre. Results during the 10 years prior to 1919 do not suggest a surplus of seed. Inspection of these two plots shows that many of the seed trees are relatively ineffective. In plot 3B they consist entirely of blackjack, which are mostly in groups, and a large proportion are diseased, due to mistletoe infection. Plot 3A has a good representation of free-standing yellow pine, but many of these are decadent and are not producing normal quantities of seed. Eliminating the unproductive and poorly situated trees, the margin above the specified minimum of four good seed trees per acre will shrink to a negligible quantity.

Great emphasis must be placed on quality and location as well as upon the number of seed trees. In many virgin stands there is a dearth of good trees so located as to give proper distribution of seed. In such cases it is better to fall below the standard requirement than to leave poor trees which sap moisture from the soil but yield negligible quantities of seed. A fact which heretofore has remained unnoticed, but which has been clearly demonstrated by the scattered seed-tree cutting, is that stump patches created by clear cutting in groups afford the best possible opportunity for immediate replacement of the trees which are removed. To secure the best results the groups should be cut clean, and seed trees should be left where they will seed these spots without invading them with their roots.

In all of the preceding discussion it has been assumed that reproduction is lacking at the time of cutting. There are extensive areas, however, which are well stocked in advance of cutting. Under such conditions the reproduction problem is greatly simplified, since all that is necessary is to leave a few seed trees to stock the openings created by cutting (usually no reproduction occurs directly under the trees, though there are exceptions to this rule), and to provide adequate protection against fire and grazing. Some damage is to be expected in logging, but experience has shown that ordinarily this is not serious. The advantages of advance reproduction are so great as to warrant special efforts to encourage the establishment of seedlings in virgin stands in which cutting is contemplated. Because of the enormous quantities of seed produced in a virgin stand, reproduction can be secured in a much shorter time before cutting than after cutting. The seedlings will grow slowly in a virgin stand, and those nearest the trees are likely to be shaded out; nevertheless, the presence of a good crop of seedlings at the time of cutting is a valuable asset. With adequate protection against fire and regulation of grazing, the open spaces in most virgin stands could be stocked in about 10 years, and by properly timing the cutting with reference to seedling crops, even the seedlings under groups of old trees could be saved.

SUGGESTIONS REGARDING PRESENT PRACTICE IN CUTTING.

How do the foregoing conclusions affect present silvicultural practice? This question can best be answered by quoting the instructions for marking western yellow pine in the Southwestern District, and adding such comments as seem warranted by the information brought to light in this investigation.

Principles of Standard Marking Practice in Western Yellow Pine, District 3, January 10, 1917.	Comment.
The basic standard.—All marking will be done with the primary object of meeting the silvicultural requirements of the stand. So far as present information indicates, this can be most uniformly accomplished by the adoption of the following standard: (1) Yellow pine trees, as distinct from blackjacks which have passed the period of rapid growth, will be marked for cutting except where, in the absence of younger and better trees, they are necessary as seed trees or to afford protection or shelter for reproduction to establish itself. (2) Blackjacks and rapidly growing intermediate trees will be left except	The principle governing the removal of trees is that the relatively young blackjack should be left in preference to the mature or overmature yellow pine. Intermediate trees represent the transition stage between blackjack and yellow pine. In marking, intermediate trees should be treated as blackjacks since they are still in the stage of active growth. Whenever there is any doubt as to whether an individual is a blackjack or a yellow pine, a safe rule is to call it a blackjack. The foregoing refers to

where by thinnings increased growth from trees left can be obtained, or where because of defect, disease or insect infestation, forest conditions can be improved by their removal. By intermediate trees is meant fast growing trees in the transition stage from blackjack to yellow pines.

Seed trees, whether left singly or in groups, should be as well distributed as possible, so as to seed the maximum area. The best seed tree is a blackjack or intermediate tree over 22 inches d. o. b., wind firm, sound and free from mechanical or fungi defects, with full healthy crown and showing evidence of bearing cones. Its physical location from the standpoint of the area it will possibly seed should also be considered.

NOTE.—These instructions in so far as they are in conflict with those given on pages 36 to 44 of the Silvicultural Handbook, supersede the latter.

It is usually unnecessary to consider the factor of protection on north slopes, moist locations, or areas where the soil is protected by oak brush or other living brush or reproduction. It should uniformly be considered on wind-swept areas, slopes exposed to drying-out influences of sun and wind, cinder soils, and dry locations where any form of protective cover is absent.

Wind-swept areas.

the future growing stock rather than to seed production.

Yellow pine, because of larger size, produces more seed per tree than blackjack, but involves more risk from windfall, lightning, and the general deterioration associated with old age.

In view of recent findings in regard to seed production, exception might be taken to the statement that blackjacks or intermediate trees make the best seed trees. Yellow pines produce more seed than blackjacks, but because of the greater desirability of the latter as growing stock, they should be given the preference, with the understanding that a greater number will be required. In practice, however, the ideal seed tree is difficult to find, and often it is necessary to leave some trees which fall below the highest standard. The usual grouped arrangement is not conducive to efficient seed production or dissemination. For this reason, increased use of thinnings in dense groups of blackjack is recommended. Thinnings within groups must, however, be made with due regard for windfall and damage to remaining trees in felling.

In accordance with the old conception of the rôle of protection, we find this idea emphasized throughout the instructions. The second footnote specifies the conditions under which shelter of standing trees should be made a primary consideration in cutting. Analysis of these conditions in the light of recent investigations is profitable. Specific reference is made to "wind-swept areas," "slopes exposed to drying-out influences of sun and wind," "cinder soils," and "dry locations where any form of protective cover is absent."

Areas exposed to unusually high wind movement undoubtedly warrant leaving a sufficient number of trees to break the force of the wind. In all excepting the most extreme cases, this will be accomplished by the number of trees usually left, that is 10 to 12 trees per acre above 11 inches di-

ameter breast high, mostly blackjack. Where the usual groups of blackjack are absent, resulting in a scattered arrangement of seed trees over a large area, the number required for wind protection might exceed the minimum required for seed production. Under these circumstances, in the most exposed situations, such as edges of "parks" or wind-swept slopes, the total number of trees above 11 inches in diameter should not be less than eight per acre. Where there is a considerable amount of tall underbrush, the number can be reduced if consistent with seed requirements.

Sun and wind

"Slopes exposed to drying-out influences of sun and wind" fall within the scope of the above discussion, in so far as the effects of wind are concerned. The influences of insolation have been discussed elsewhere in this report. It is shown that seedlings so situated as to be shielded from the sun during the greater portion of the day will be shaded out later in life. Beyond the zone of maximum shade, where the sunlight is sufficient to permit normal development, the benefits of partial shading will be at least in part offset by root competition from the trees. The only appreciable benefit which the shade of standing trees may be expected to yield is in assisting germination and early establishment. To take advantage of this benefit it is necessary to fell the trees before the seedlings begin to suffer from lack of sunlight. Although such a silvicultural system is generally impractical under present economic conditions, it might be applied to limited areas whose value warrants special treatment.

In general, it may be said that for western yellow pine in the Southwest, the leaving of mature trees beyond seed requirements, purely as a protection against excessive insolation, is unwarranted. Since in this region the sites exposed to excessive insolation; that is, steep slopes of southerly exposure, are also subject to unusually

high winds, they will often require the leaving of trees above the minimum for seed production; but in such cases the additional trees will be left for the purpose of protection against wind rather than sun.

Cinder soils

The cinder soils here mentioned refer to a special condition in the volcanic cinder cone region on the east edge of the Coconino National Forest. Coarse black or dark red cinders cover a usually clayey soil to depth ranging from less than an inch to a foot or more. It also happens that this region receives less rainfall than the yellow pine type as a whole. Pine seeds germinate with difficulty in the cinders, because the surface layer dries out rapidly under exposure to sun and wind. Where the cinders are more than an inch deep, seedlings occur most commonly where the soil is covered by herbs, shrubs, or litter, or in the shade of trees. The deeper cinder areas are bare of grass or other herbaceous growth. Under such conditions germination takes place only in the shade of trees or shrubs or in spots where leaf litter has accumulated. Although nearly all of the seedlings which start in the shade of trees die, a few survive in the outer edges of the shade area. Because of the extremely critical condition with regard to germination, the leaving of trees to shade the soil is warranted in the cinder region where ground cover is absent. The silvicultural practice previously mentioned, in which cutting is deferred until a crop of seedlings has become established under the virgin stand, is recommended for cinder areas of the extreme type.

Dry locations where any form of protective cover is absent.

The most common forest areas answering this description are extreme forms of cinder lands, badly eroded slopes, gravel slides or other sites destitute of soil. Under all of these conditions cutting should be greatly restricted if not entirely prohibited. Conditions similar to the above in effect may obtain on clay soils where the surface has been

packed and the herbaceous cover destroyed by overgrazing. Wherever the soil remains, however, overgrazing usually leaves a considerable amount of plant cover in the form of unpalatable weeds and shrubs. Clumps of rabbit brush, pingue, sage, and coarse bunch grass, if not so dense as to create excessive root competition, assist pine seedlings in getting started, and their shade is not sufficient to interfere seriously with later development. Wherever a normal soil layer is present, and there is even a scattering ground cover, the leaving of trees beyond the needs for seed production and protection against extreme wind will retard rather than promote yellow pine reproduction. This applies even more to dry than to moist sites, where drought is not due to lack of soil.

Second cut.—Whether or not sufficient trees are being left to provide for a second cut need not be considered. Marking as indicated above contemplates that all vigorously growing blackjacks and intermediate trees will be left except where thinnings are desirable or where they are badly defective, diseased, or insect infested, as indicated later in this memorandum. A second cut will be merely incidental to marking on this basis and will be determined by future market conditions.

It is contemplated that the trees left for reproductive purposes will form the basis for another logging operation in from 50 to 100 years. For this reason it is desirable to leave relatively young trees which while they are producing seed will also increase in volume. As far as possible, the leaving of overmature trees which are almost sure to be lost before another cutting can be made, is to be avoided. The possibility of a second cutting is contingent upon there being a sufficient volume of timber on the ground within 50 to 100 years to make logging economically feasible. The point which the instructions evidently aim to convey is that trees which because of maturity or other circumstances can not be expected to contribute substantially to the increment of the stand, should not be left for the purpose of providing for a second cut unless they are needed for reproductive purposes; that is, the production of seed, and in some cases wind protection. Aside from the risk of total loss by death, it is clearly poor business to allow trees of this character to occupy space which can be used to much better advantage by

Application of standard.—The application of the above standard to conditions on the ground will be subject to the following considerations:

1. To give the purchaser at least the amount in volume, from the sale unit as a whole, which is guaranteed by his contract.

2. Where reproduction is not established or is inadequately established and blackjacks or intermediate trees are not present to assure adequate seeding and protection, sufficient yellow pine trees will be left to meet these silvicultural requirements. The number of such trees required for seed and protection or shelter necessarily varies, depending upon their condition. For average conditions, where reproduction is not established, at least three (3) windfirm good-crowned trees less than 25 inches d. b. h. should be left per acre, if available; if the only suitable trees to leave are all over 25 inches d. b. h., the number may be reduced to two (2) per acre. If, however, the condition of the trees or the condition of the area with respect to exposure, dryness, etc., is such that, in the judgment of the marker, adequate protection or seeding will not be afforded, a greater number should be left.

3. Where sufficient blackjacks and intermediate trees for seed and shelter are present, all yellow pine may be cut.

4. In stands containing a mixture of yellow pine, blackjacks of merchantable size, and poles, all yellow pines may be cut except where needed in openings for seed or protection, and blackjacks and intermediate trees may be marked for cutting, if their removal is justified from a thinning standpoint, or if badly defective or diseased, provided they are not needed for seed or protection.

young trees. They not only shade out seedlings within a considerable area around their bases, but will retard the growth of young trees within the entire area occupied by their roots, which may extend over a radius of 100 feet.

Examinations prior to making a sale should determine the amount of timber which may be removed without danger to reproduction.

The blackjacks alone are rarely adequate for seed production, because the great majority of the trees in this class are too small to bear much seed, or occur in large groups where their crowns are poorly developed, and their seed is not effectively disseminated. It has been shown under "Seed Supply" and "Cutting" in this report that trees below 21 inches in diameter, almost exclusively blackjack, are ordinarily a small factor in seed production. The average yield of blackjacks over 11 inches diameter breast high in a good seed year has been placed at one-half pound per tree, but for blackjack over 20 inches the figure would be in the neighborhood of 1½ pounds. Yellow pine of the type usually left after cutting will produce about 2½ pounds per tree. Exceptionally good seed trees may produce over 10 pounds. In the attempt to fix a general guide applicable to large areas where detailed classification of the trees is impractical, the elimination of trees below 21 inches is recommended. On this basis, the minimum number of seed trees has been placed at four per acre. The instructions specify that where it is necessary to supplement the blackjacks with yellow pines, the number per acre should be not less than three windfirm good-crowned trees, if under 25 inches, or two if all are over 25 inches. The wording implies that trees over 25 inches in diameter should not be left if smaller ones are available. This provision is made because the larger trees are less desirable as forest cap-

ital on account of relatively slow growth and greater susceptibility to lightning, windthrow, and decay. Recent investigations, however, show that few trees under 25 inches in diameter have reached the highest stage of seed bearing. In view of this fact it seems advisable to revise the instructions so as to provide for at least four trees per acre where the diameters fall between 21 and 25 inches. If all the trees measure over 25 inches, and if they are well selected, two per acre may suffice; but three per acre is preferable, especially if some individuals are not strictly up to standard. In such cases too much emphasis can not be placed upon the importance of selecting the very best seed trees available. A first class seed tree in the yellow-pine class may yield 10 pounds of seed in a single year, whereas a poorer seed tree of equal diameter, representing an equal investment in timber value, and drawing an equal amount of moisture, needed by young growth, may in the same year produce only 1 pound of seed.

5. Where adequate reproduction is established, but is less than the pole stage, and there are few or no blackjacks or intermediate trees.

(*a*) Yellow-pine seed trees should be left as safety trees, if the bulk of the reproduction is less than two (2) feet in height, and where needed to seed in or shelter blank areas.

In addition to blanks which may exist prior to cutting, provision should be made for seeding up the open spaces which are created by the removal of trees. Underneath and extending from 20 to 40 feet around large tree groups, the ground is usually bare of seedlings as well as herbaceous growth. These spaces afford ideal conditions for reproduction after the trees are felled, provided they are well seeded and grazing is properly regulated. Where the group arrangement is strongly developed, these spaces, or stump patches, may occupy 25 per cent of the total ground area after cutting.

(*b*) All yellow pines may be cut if the area is well stocked with reproduction two (2) feet and over in height.

As in the above case, provision should be made for seeding the stump patches created by felling large groups of trees. Usually there will be enough large blackjacks for this purpose; nevertheless, the matter should be kept in mind.

6. In stands containing only blackjacks and intermediate trees, marking will be on an improvement basis, the object being to mark only such trees, the removal of which will release other trees and result in increased growth in the stand left, or will rid the forest of badly diseased or insect-infested specimens. Severe thinnings should be guarded against, particularly in poorly stocked stands. Similarly, the marking of dominant, fast-growing young trees, whose removal will open up a bunch of small suppressed trees, which it is clear can never recover from suppression, should be carefully watched. The principle of improvement thinnings should always govern.

No comment.

7. *Mistletoe.*—It is felt that mistletoe can not in all cases be eliminated in one cutting without too great a sacrifice of silvicultural requirements. Mistletoe infections should be classed as heavy, moderate, and light.

(*a*) All heavily infected trees should be cut regardless of the condition of the stand after cutting.

(*b*) Moderately infected trees should always be marked, except where there are no other trees available to leave as seed trees.

To rid a stand entirely of mistletoe would in many cases involve clean cutting and planting. Until more intensive management becomes economically possible this remedy can not be applied. In some cases it might be feasible to practice the scattered seed-tree method of cutting. Only trees which are entirely free of mistletoe should be left, and infected young growth should be destroyed. As few as two large seed trees per acre might reseed such areas.

It is felt that moderately infected trees should be left as seed trees rather than to make clear cuttings because of the infection. This, however, applies to large areas rather than to small openings or small areas which have a chance for reproduction from surrounding trees and where the infection might be completely cut out without opening up the forest too extensively. Moderately infected trees will be left for soil protective purposes only on the most adverse sites, where their need for this purpose is clearly evident.

What data are available indicate that lightly infected young trees will, as a rule, continue to grow and produce seed for 100 years. For moderately infected trees this period will be shorter, but comparatively few will die before the next cutting. The chief danger is infection of young growth. Under present conditions, our efforts will of necessity be confined to such control as is possible in connection with logging operations. Forest officers should be on the lookout for newly infected areas, where by cutting or pruning a few trees the spread of the parasite may be checked. A great difficulty in such control is that the presence of mistletoe is not readily detected until it has gained considerable headway. Thus, even though an effort were made to cut every infected tree, some trees bearing enough mistletoe to perpetuate it and infect reproduction would escape. To be effective, therefore, the control meas-

(*c*) Lightly infected yellow pines will be left when uninfected trees are not available for seed and protection. On areas adequately stocked with reproduction, all infected trees will be cut. Lightly infected blackjacks and intermediate trees on areas on which reproduction is not established, will not be cut when otherwise thrifty and sound except where thinnings to obtain increased growth are desirable or where reproduction, as noted above, is established. Such thinnings may be slightly heavier than in uninfected stands, but it is not felt that in lightly infected blackjack stands where reproduction is not established, vigorously growing and thrifty trees should be radically sacrificed.

8. *Defects due to other fungus diseases.*—All trees containing other fungus diseases will be marked for cutting where sound, healthy trees are available as seed trees and for protection. Where satisfactory trees can not be left, the extent to which the ures would have to be repeated at intervals of something like 10 years. Here again we are confronted by the physical impossibility of carrying out the work with the men and funds available. Nor is it certain that the effects of mistletoe are sufficiently serious to warrant the expense of complete control. More information is needed in regard to rate of spread, and the time required for the parasite to injure a tree.

The present instructions in regard to the removal of mistletoe-infected trees cover the subject satisfactorily, except that there seems to be a need for more specific definition of the different degrees of infection. Lack of a clear understanding on the part of field men of what is meant by heavy, medium, and light infection may lead to serious misinterpretation of instructions. The following standards are proposed:

Heavy infection.—Trees which show clear evidence of injury by mistletoe, as indicated by distorted, dead, or dying branches in more than one-half of the crown. The condition of the crown, rather than the visible amount of mistletoe, will ordinarily be the criterion, although the presence of large quantities of mistletoe in otherwise apparently normal crowns will class the tree as heavily infected.

Medium infection.—Injury by mistletoe in the form of distorted branches, but few dead or dying branches in the lower one-half or less of the crown. Mistletoe is usually present in appreciable quantities.

Light infection.—Mistletoe present in small quantities limited to the lower one-fourth or less of the crown. No dead or distorted branches. The presence of a single sprig of mistletoe is sufficient to class the tree as lightly infected.

It is presumed that the appearance of any disease which might seriously endanger the stand would call for the removal of all specimens affected. As far as is known, no such diseases occur in the Southwest.

disease has affected the tree must, of course, be taken into consideration. A badly diseased tree should not be left even though seeding and protection purposes must be sacrificed on small areas. On the other hand, a tree which shows evidence of disease but which will clearly remain thrifty for 10, 20, or 30 years is better left as a seed tree or for protection where needed than no tree at all.

9. *Defects of mechanical nature.*—These include fire scars or cat faces, broken tops, lightning cracks, forked boles or tops, crooks, resin flow, etc. In this district, resin-flow wounds or "sores" a foot or more in length usually indicate the tree to be on the decline. Marking will, in so far as conditions permit, aim to remove not only diseased and insect infested trees in accordance with the above standards, but likewise all badly defective trees, yellow pines uniformly, blackjacks and intermediate trees whose growth is permanently retarded by the defect, provided, in both instances, other trees are available in the form of seed trees or permanently established reproduction. Therefore, defective trees will be marked for cutting except when more valuable for seed protection or future growth. A tree which is not too badly defective but is apparently thrifty is better left for seed and protection than no tree at all. The marking of such defective trees which are not now merchantable and which can not be counted on for increased growth will be aimed at where reproduction is established or suitable seed trees are available, and in future contracts will be fully covered.

With the possible exception of forking, which may be hereditary, mechanical defects of the character mentioned apparently do not seem to impair the value of a tree for reproduction, unless the area of the crown is reduced. Therefore, in the absence of sound trees, defective trees may be left for reproduction. Some studies have shown higher germination for trees with certain mechanical defects than for sound ones; but the evidence is not sufficiently conclusive to warrant leaving defective trees where they are not needed.

10. *Insect infestation.*—All trees infested with living pine beetles will be marked for cutting, regardless of their need for seed and protection.

No comment.

11. *Windfall and lightning.*—On areas of high windfall or lightning hazard, it may often be necessary to leave more trees, especially if yellow pines, than indicated in the above standard. As a protection against windfall, the leaving of trees in groups, as far as possible, is advisable. This is particularly true of yellow pine trees which must be left because of the absence of blackjacks. Yellow pine trees are more subject to windfall than are blackjacks. Avoid as far as possible the leaving of tall trees or those containing more than four logs. Avoid wherever possible the opening up of trees which have previously been protected by others.

From the standpoint of seed production and the effective utilization of light and soil, the arrangement by groups is undesirable. But it is now generally accepted that if the majority of the trees in an even-aged group are cut, the remaining members will be subject to windfall. For this reason it is desirable to treat the group as a single unit, either leaving the entire group, except for light thinnings, or cutting the entire group. In either case, however, it is often possible to make exceptions of individual trees. One-sided or leaning trees are liable

The principles and policies herein established are effective from date of issuance of this memorandum."

O. M. BUTLER,
Assistant District Forester.

Approved Jan. 23, 1917.

PAUL G. REDINGTON,
District Forester.

to be broken down by heavy snows. The policy of clean cutting groups coincides with what has been said regarding the desirability of creating stump patches as a means of promoting reproduction.

BRUSH DISPOSAL.

METHODS IN USE IN THE SOUTHWEST.

Three methods of brush disposal are practiced by the Forest Service in the Southwest, namely, piling and burning, scattering,[17] and pulling tops. The terms are essentially self-explanatory. In piling and burning all branches are cut into convenient sizes for handling and placed in compact piles, usually not exceeding 8 feet in diameter, and, so far as possible, at safe distances from living trees and young growth. Burning is carried out when weather conditions are such as to prevent the fire from spreading, that is, during the summer rainy season or preferably right after the first snows. Scattering, as the term implies, consists of scattering the branches in open spaces. In pulling tops, the unused tops are dragged by a team into the openings, where they are left without further treatment. The branches cut from used portions of the stem are usually left as they fall, thus creating a condition resembling what in some regions is designated as "lopping." It differs from the latter in that the branches often project several feet into the air, whereas in lopping they are usually cut, or lopped, so that they will lie close to the ground. Although associated with pulling tops, this form of disposal creates a more or less distinct condition and will be recognized as such in the discussion which follows. It is a uniform rule in all of the methods to leave no brush close to living trees (the minimum distance varying from 15 to 25 feet) and to keep it away from reproduction as far as possible. Of the three methods, pulling tops has been most extensively practiced on the Coconino and Tusayan National Forests, while on other National Forests in this region scattering has been the general rule. In all of the methods which involve leaving brush on the ground fire lines 100 to 200 feet wide are made by piling and burning.

INVESTIGATIONS REGARDING THE EFFECTS OF SCATTERING BRUSH, 1909–1918.

There is a widespread opinion among foresters in the Southwest that the chances for reproduction are improved by leaving the brush on the ground in some form or other, either scattered, lopped,

[17] This method is officially designated as "lopping and scattering," but is here referred to as "scattering" in order to avoid confusion with "lopping."

or pulled. This opinion is based upon the observation that in old cuttings, where reproduction is generally deficient, more seedlings are usually found along logs and tops than in the open. The explanation generally accepted is that the projecting branches protect young seedlings against excessive sun and wind, and that the leaf litter and twigs falling on the ground form a mulch which is effective in conserving soil moisture. In order to test this theory, experiments were initiated in 1908 and have been carried on intermittently until the present time.

The earlier investigations were confined to a test of the effects of scattering. Progress of reproduction was compared on plots covered with scattered brush and on plots having no brush cover. Records of seedling establishment were supplemented by studies of physical conditions, particularly the changes in the brush cover from year to year, and the effect upon soil moisture. An experiment initiated in 1908 has given negative results with reference to seedling survival, whereas one initiated in 1914 shows a decided advantage in favor of scattered brush. Later investigations have shown that this discrepancy is due to the fact that we are dealing with two sets of conditions. The essential point of difference is that in the 1908 experiment a dense stand of bunch grass was allowed to grow unhampered even by grazing throughout the entire period of 13 years, whereas in the 1914 experiment the herbaceous vegetation was eliminated at the start by plowing. Determinations of soil moisture in 1909, 1912, 1919, and 1920 show a consistently higher moisture content underneath the brush than in open situations. The investigations are presented in chronological order.

1908 Experiment.

Seedling survival.—Brush was scattered on an area of 126 acres in the cinder region about 8 miles east of Flagstaff. The branches cut from the felled trees sufficed to cover less than half the total ground surface. Since this area is typical of the most extreme drought conditions in the yellow-pine type, it was anticipated that the effects of brush upon reproduction would be decisively demonstrated. After 12 years, however, no appreciable difference between brush-covered and open spots could be discerned. In 1909 a considerable number of seedlings started both in the brush and outside, but in 2 years nearly all had disappeared. Very few seedlings have started since 1909. Even in 1919, when a bountiful seed supply and ideal conditions for germination resulted in abundant reproduction generally on the Colorado Plateau, no seedlings appeared on this area, for the reason that the 1918 seed crop was almost a total failure in this particular locality. Sample plots from time to time have yielded re-

sults as shown in Table 21. From this it is evident that if the brush was beneficial it was not sufficiently so to aid reproduction in a measurable degree.

TABLE 21.—*Effect of brush on germination and survival of seedlings, cinder area.*

Date of examination.	Number of plots.	Total area.	Number of seedlings per acre.[1]		Remarks.
			Brush.	No brush.	
		Sq. feet.			
1909. Aug. 19	10	500	13,100	12,200	1909–10 counts all on the same plots; all seedlings of 1909 germination.
Sept. 22	10	500	7,800	12,200	
Nov. 19	10	500	1,950	6,100	
1910. Sept. 13	10	500	218	2,395	82 per cent of "no brush" on 1 plot.
1911. Sept. 9	10	5,000	35	87	All seedlings of 1909 germination.
1912. July	10	1,000	87	174	New plots; includes some of 1911 germination.
		Acres.			
1913	10	1.2	27	30	Includes a few originating after 1909.
1920. August	.....	1.5	50	53	Ages 4 to 10 years; all germinated 1909 or later.
1919. General, both brush and no brush.	.....	16	80	.....	Ages, 4 to 20 years.

[1] 1909 and 1910 records are for identical plots. After 1910 new plots were selected for each examination.

Physical conditions.—In conjunction with the seedling records, experiments were conducted with the object of determining in a quantitative way the effect of a brush cover upon physical conditions which were thought to have an important influence upon seedling growth. Some of these effects are so obvious as to require no experimental proof. For example, it is known from observation that brush cuts off the light to such an extent as to endanger the life of seedlings beneath it. Other effects, such as smothering, are equally obvious. Certain other anticipated effects are less easily demonstrated. It is reasonable to suppose that seedlings situated so as to be only partially screened may be benefited by reduction of excessive transpiration, protection against wind and frost, and conservation of soil moisture without suffering the injurious effects of too much cover. In the fall of 1908 thermometers placed under a cover of green branches at night showed temperatures from 1° to 5° F. higher than those a few feet from the brush. During the same year unprotected first-year seedlings were killed by an early freeze, while on a plot covered by brush they were uninjured. Even a light screen reduces transpiration; but no experiments have been conducted to prove how effective a light brush cover may be.

Soil moisture.—Most of the experimental work has centered on the question of soil moisture. How effective is a brush cover against loss of soil moisture? The results of samplings in 1909 and 1912 are given in Table 22 and Figure 12. No determinations of wilting coefficient were made at the time these samples were taken. Determinations in 1920 for samples secured in the immediate vicinity of

the original ones give values of 6.5 per cent at a depth of 2 inches, 8.9 per cent at a depth of 6 inches, and 12.5 per cent at a depth of 12 inches. The 6-inch coefficient is probably approximately correct for the 4 to 8 inch moisture samples.

TABLE 22.—*Total soil moisture (percentage of dry weight), brush experiment, cinder area, 1909 and 1912.*

	1909.											
	May 1.		May 29.		July 3.		Aug. 5.		Sept. 4.		Oct. 4.	
	0 to 4 inches.	4 to 8 inches.	0 to 4 inches.	4 to 8 inches.	0 to 4 inches.	4 to 8 inches.	0 to 4 inches.	4 to 8 inches.	0 to 4 inches.	4 to 8 inches.	0 to 4 inches.	4 to 8 inches.
Dense brush	14.6	.....	9.6	14.2	6.5	11.7	13.3	16.8	21.2	21.5	16.4	.....
No brush	7.1	.....	2.9	10.8	5.4	8.7	10.0	14.2	21.0	21.7	10.9	.....

	1909.		1912.									
	Nov. 6.		June 11.		June 26.		July 12.		Aug. 7.		Sept. 12.	
	0 to 4 inches.	4 to 8 inches.	0 to 4 inches.	4 to 8 inches.	0 to 4 inches.	4 to 8 inches.	0 to 4 inches.	4 to 8 inches.	0 to 4 inches.	4 to 8 inches.	0 to 4 inches.	4 to 8 inches.
Dense brush	6.9	10.6	11.0	12.3	6.4	9.2	4.5	6.8	14.5	14.5	7.0	7.4
Light brush	.....	.....	10.0	12.6	4.1	8.5	2.4	6.1	19.	14.3	5.9	7.0
No brush	3.6	9.6	9.4	11.2	5.1	7.2	3.8	5.3	15.	15.3	5.5	8.7

Both the 1909 and 1912 series show a substantial margin in favor of the brush cover during the foresummer. After the summer rains are well in progress, all values are so high that minor differences are insignificant. There is, however, a tendency for the moisture content to be lower at times under the cover, due no doubt to interference with rain reaching the soil. In the autumn the margin in favor of the brush appears to be uncertain. The 1909 series shows a difference of but 1 per cent at 4 to 8 inches on November 6. In 1912 the balance was actually in favor of the open areas. At the time this relation was first observed it was thought to be due to abnormal samples or some error in determining the moisture content, but more recent experience has shown such occurrences to be not uncommon. The explanation is found in the activity of grass and other vegetation. Usually all plants are killed directly under a heavy mass of brush, but survivors in the margin of the brush develop extraordinary luxuriance, with the result that they may reduce the soil moisture to a lower level than that which prevails at some distance from the brush. This condition is more

likely to exist in the fall than in the spring, because most of the plants attain their maximum size and therefore make the greatest demands upon soil moisture near the close of the growing season. All moisture studies show a sharp decline immediately after the cessation of the summer rains. The 1909 series represents the in-

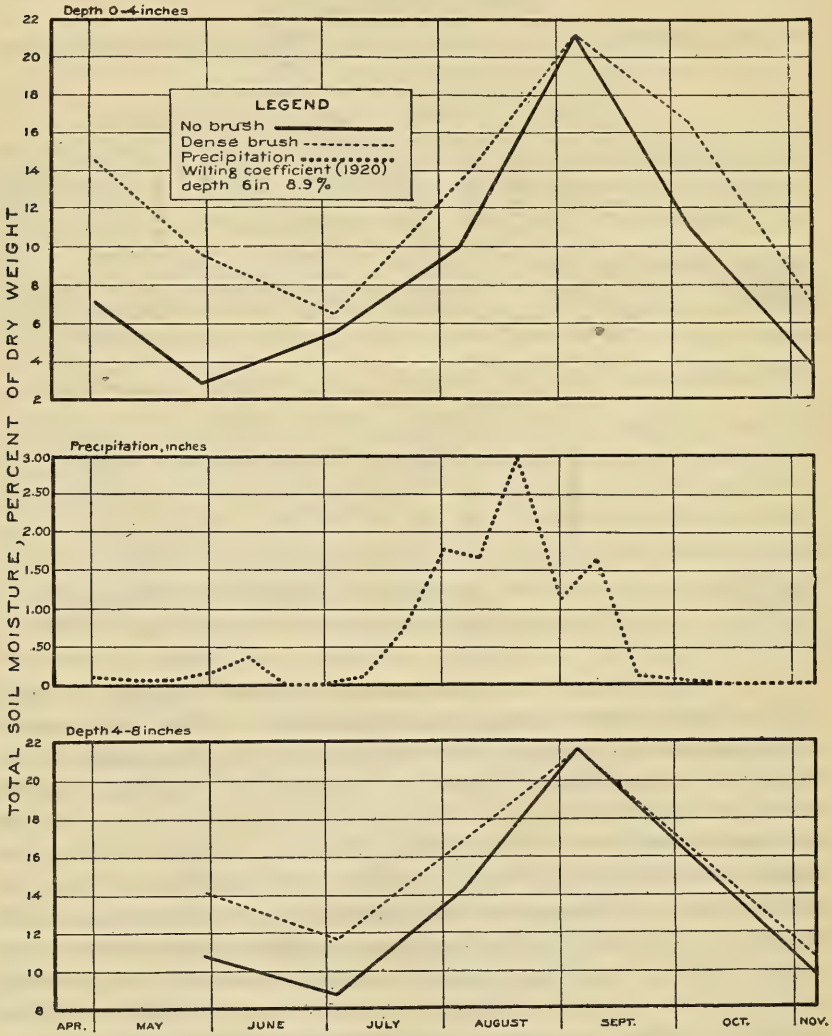


FIG. 12.—Total soil moisture brush experiment cinder area, 1909.

fluence of brush during the first season after scattering. During this year the grass was subdued to a great extent by the brush. By 1912, however, the grasses which had not been killed out, that is, the bunches under the lighter cover and in small openings, had grown decidedly rank.

Although the experiment on the cinder area has been disappointing as a decisive demonstration of the effects of brush disposal upon reproduction, it has yielded valuable information of a more general character. First of all, it shows that under protection against fire and unregulated grazing, reproduction, though extremely slow, will eventually succeed even on such adverse sites as this one. Since about three-eighths of the seedlings were on the ground before the cutting, the importance of preserving advance growth on such sites becomes evident. Notes on the condition of the brush from time to time yield a valuable record of the rate of disintegration and other changes.

Progressive changes in the character of the cover.—From the time the branches are placed on the ground until they are decomposed, involving a period of from 15 to 20 years, the cover undergoes a series of successive changes which may be assumed to be accompanied by corresponding changes in the effect upon reproduction. These effects may range from beneficial to positively detrimental. Several more or less distant periods or stages of disintegration have been recognized. In green brush the bowed form of the branches usually prevents them from lying flat, and consequently they form a screen from a few inches to 2 feet or more above the soil surface. This applies particularly to scattering. In pulled tops, the lowermost branches are pressed down, while the others project into the air. The density of the screen depends upon the density of the branches and foliage. Plate XV, Figure 1, and Plate XVIII, Figure 1, give an idea of the character of the cover during first and second seasons. Usually the sun's rays are only partially excluded, and the air circulates freely underneath the cover. In this stage falling seeds readily penetrate the cover, excepting where it is unusually dense. Germination is favored by the conservation of surface soil moisture; but where the cover is dense damping off may become serious, and subsequent development is retarded by lack of sunlight. If not more than half the sunlight is cut off, most of the seedlings should survive. Heavy snows tend to flatten out the branches and bring the entire screen closer to the ground. Here again density is important. If the cover is close, the snow tends to pile on top, pressing down the branches and crushing seedlings which may be underneath, whereas if the brush is more open the snow sifts through, settles underneath, and thus helps support the load. During the second season the boughs will be closer to the ground, and some leaf tufts will be matted down; all the leaves will be brown, although mostly still remaining on the stems. On the whole, the character of the cover is not very different from that of the first season. But a new factor enters in the form of competing vegetation. When

the brush is first laid on the ground it smothers a portion of the native vegetation. If the cover is dense, grass and other plants may be entirely killed in patches. This may result in conservation of soil moisture; but more often surviving plants in the edges of the cover develop so vigorously that they soon appropriate all the surplus moisture. This condition is especially noticeable where the brush is close or where unlopped branches project so as to exclude grazing animals.

The effects of brush during the first two years, which practically covers the first stage, may be briefly summarized as follows: Conservation of surface soil moisture under the brush favors germination; young seedlings are protected against wind, frost, and excessive isolation, but they are exposed to increased danger from damping-off, excessive shading, smothering, and crushing, and in some cases to injurious competition for soil moisture. The net results vary with local conditions and seasons, but, on the average, the end of the second stage is likely to show fewer seedlings on brush-covered than on open plots.

In the third and fourth years the needles fall, and the overhead screen is in part transformed into a surface mat. In scattering the cover is lighter and closer to the ground than in other forms of brush disposal. The bare branches, however, still form a light screen. Where the surface mat becomes thick it interferes with germination and induces shallow root development. Where it is not over one-half inch thick, however, it is a distinct aid to germination, especially on soils which have a tendency to dry out quickly at the surface, such as cinders or clays. A heavy fall of needles smothers seedlings. It has been observed that nearly all seedlings directly under the leafy portions of a branch are usually killed during the first or early second stage, but that many survive in the small spaces between branches and under the less leafy portions. Once the seedlings are safe from being covered the needle mat is decidedly beneficial in conserving soil moisture by checking evaporation. Herbaceous vegetation, however, is likely to become very luxuriant. The needle-mat stage continues about five years. During the latter part of this period the litter of needles is augmented by fallen twigs. On the whole, this stage seems to retard rather than promote the establishment of seedlings.

The third and final stage begins from 7 to 10 years after cutting, and continues 8 to 10 years. This period represents a process of advanced disintegration. The needle mat eventually becomes reduced to a thin layer of semidecomposed material suggesting a forest mold. The branches succumb to the action of the dry rot caused by the fungus *Lenzites sepiaria*[18] and are broken down by snow and grazing

[18] The fungi concerned in the rotting of slash in the Southwest are discussed by W. H. Long, "A new aspect of brush disposal in Arizona and New Mexico," Proc. Soc. Am. For. Vol. X, No. 4, 1915.

animals. A normal grass cover returns, excepting in places where the brush was unusually dense. Of special importance is the thin layer of semidecomposed organic matter covering the surface of the soil. As demonstrated under "Herbaceous Vegetation," this material is a decided aid to germination. In scattered brush this surface layer usually disappears in from 10 to 15 years, but where large quantities of brush are concentrated, as in piling or pulling tops, it may last 25 or 30 years. The final stage is, on the whole, favorable to reproduction.

1914 Experiment.

More decisive results have been secured on another area near the Fort Valley Experiment Station. This site receives 2 or 3 inches more rainfall and the soil is clayey and is not covered with cinders. Altogether it is more favorable for reproduction than the cinder area east of Flagstaff.

In July, 1914, one-tenth acre was sown broadcast to western yellow pine on plowed ground under fence. In anticipation of large consumption by mice and chipmunks, as is usually the case when a small isolated plot is sown, the seed was scattered very thickly, 10 pounds being used on this plot. A brush harrow was employed to cover the seed. A strip 15 to 18 feet wide all around the area was sown heavily with old seed with the hope of diverting the attention of rodents from the prepared plot. The season was unusually favorable to germination and establishment of seedlings. A dense stand was secured over the entire plot. After germination, three strips 5 feet wide and 1 chain long, extending across the plot on the north and south sides and in the middle, were laid out. Green pine branches were scattered lightly over the middle strip, leaving the other two uncovered. Counts were made on a plot 5 by 10 feet in size in the middle of each strip. The results are shown in Table 23.

High mortality occurred on all plots after, as well as during, the first year. On the whole, however, the loss is considerably less than that usually experienced under average forest conditions in this region. The severe damage by snow in the winter of 1915–16 is abnormal, but damage by white grub is a common occurrence. The greatest loss took place on the plots on which no brush was scattered. The two untreated plots showed, on an average, less than half as many seedlings per square foot as the brush-covered plot. For the entire strips the ratio in 1919 was three to eight in favor of the brush-covered area.

TABLE 23.—*Effect of brush cover on seedling survival, plowed ground, Fort Valley area, 1914.*

Date.	Number of seedlings per square foot.		
	Plot 1, no brush.	Plot 2, brush-covered.	Plot 3, no brush.
Aug. 16, 1914	3.1	6.7	8.5
Oct. 28, 1914	2.3	6.0	7.4
June 30, 1915	1.9	3.6	5.1
May, 1916 [1]	.....	.....	.....
Summer, 1917 [2]	.....	.....	.....
Summer, 1918 [3]	.....	.....	.....
Apr. 19, 1919	.14	.70	.54

Survival from Aug. 16, 1914, to Apr. 19, 1919:	Per cent.
Brush	10.5
No brush (average of 2 plots)	5.9

[1] No counts. Many seedlings broken at ground line by heavy snow of preceding winter.
[2] No counts. White grub killing all seedlings in patches.
[3] No counts. White grub active. Nearly all seedlings on east side dead or dying.

This experiment demonstrates what may be accomplished by the application of brush when associated with favorable conditions of soil and moisture. It is fair to conclude that brush was in this case beneficial to reproduction, but this does not mean that brush will offset a deficiency in seed supply, a poor seed bed, and extreme drought, such as were encountered in the 1908 experiment. It should be noted that the brush was applied *after* germination. Notes in connection with annual examinations show that the seedlings which were *directly under* the brush died, and the survivors were in the small comparatively clear spots *between* the branches. This relation is still apparent on the ground. (Pl. XVII, Fig. 2.)

The experiment also indicates a beneficial effect due to plowing. Studies in 1920, which will be described later, indicate that without the plowing, which destroyed the native vegetation on this plot, a lower survival would have been secured on the brush-covered than on the open strips. On the seeded but uncultivated border around the plowed plot very few seedlings were in evidence at any time. Although this is not a fair comparison, owing to the inferior quality of the seed on the unprepared ground, it is known that a good percentage of the old seed was viable, and therefore the results are at least significant. In apparent contradiction to these results stand those described under "Herbaceous vegetation," in which sample plots 1B, 3A, and 3B showed less germination where the ground had been cultivated than where it was left in the natural state. The difference is readily explained by the fact that on sample plots 1B, 3A, and 3B practically no seed fell until four years after cultivation, with the result that the soil became packed, while in this experiment the seed was sown and harrowed in immediately after plowing.

F—49194A

FIG. 1.—ONE YEAR AFTER CUTTING; NEEDLES STILL ON, FORMING DENSE SCREEN WHICH IS UNFAVORABLE TO REPRODUCTION.

F—49220A

FIG. 2.—THREE YEARS AFTER CUTTING; NEEDLES FORMING DENSE MAT WHICH INTERFERES WITH GERMINATION.

F—160233

FIG. 1.—TEN YEARS AFTER CUTTING, PARTLY BROKEN DOWN BY GRAZING. OVERGRAZING PRIOR TO LOGGING ELIMINATED THE GRASSES.

The soil is a heavy clay. Under these conditions brush favors reproduction.

F—161930

FIG. 2.—PULLED TOPS IN BUNCH GRASS, 2 YEARS AFTER CUTTING. THE GRASS IS NOT GRAZED IN THE BRUSH, AND THEREFORE CHOKES OUT PINE SEEDLINGS.

PULLED TOPS.

F—43879A

FIG. 1.—GOOD RESULTS FROM BROADCAST SOWING ON PLOWED GROUND IN 1914.

The seedlings are most numerous in a strip which was lightly covered with brush after germination.

F—43890A

FIG. 2.—NEAR VIEW OF BRUSH-SCATTERED STRIP ABOVE. FEW SEEDLINGS SURVIVED DIRECTLY UNDER THE BRANCHES.

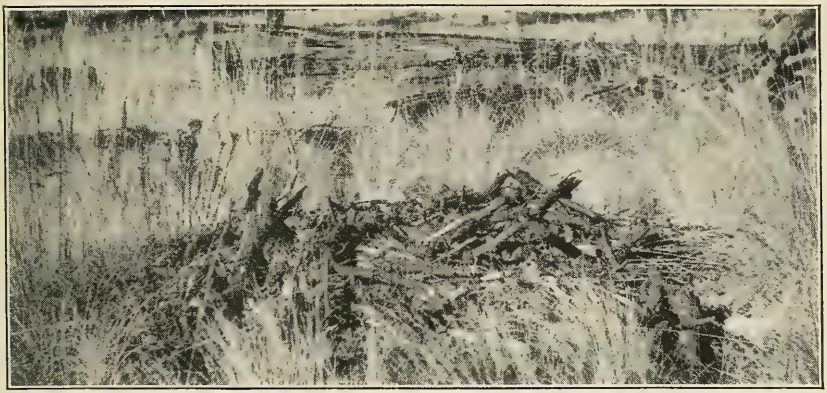
F—81279

FIG. 1.—SCATTERED BRUSH 3 MONTHS AFTER CUTTING, 1908.

F—13642 A

FIG. 2.—SCATTERED BRUSH 4 YEARS AFTER CUTTING. THE TALL GRASS IS DETRIMENTAL TO REPRODUCTION.

SCATTERED BRUSH.

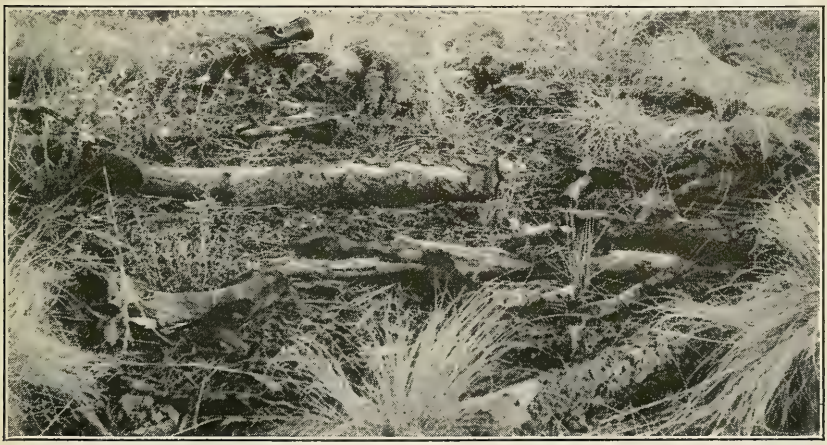


F—49191A

FIG. 1.—BRUSH PILE, 12 YEARS OLD, NO GRAZING. THE LUXURIANT GROWTH OF GRASS SUPPRESSES THE PINE SEEDLINGS WHICH WOULD OTHERWISE BECOME ESTABLISHED IN THE EDGES OF THE PILE.

F—49177A

FIG. 2.—SAME AS ABOVE; BUNCH GRASS CROPPED DOWN BY CATTLE. UNDER THESE CONDITIONS THE EDGES OF PILES AFFORD GOOD CONDITIONS FOR SEEDLINGS WHICH DRAW UPON THE MOISTURE STORED UNDER THE BRUSH.



F—150510

FIG. 3.—BURNED BRUSH PILE, 11 YEARS AFTER THE FIRE. NEGLIGIBLE AMOUNTS OF HERBACEOUS VEGETATION HAVE ENTERED. SEEDLINGS OF 1919 GERMINATION ARE ABUNDANT ON SUCH SITES WHERE PROTECTED AGAINST GRAZING.

PILED BRUSH.

INVESTIGATIONS FROM 1919 TO 1921.

SOIL MOISTURE.

Since all available information pointed to soil moisture as the key to the situation, this phase of the problem was again attacked in 1919, and the study continued through 1920. Soil-moisture determinations were made at intervals of from two weeks to a month through the growing season. The samples were taken near the Fort Valley Experiment Station on plots on which brush had been placed with a special view toward simulating conditions in typical brush scattering. Having in mind the discrepancies in earlier experiments, where samples were taken more or less at random, samplings were confined to localized areas, with the object of eliminating as far as possible inequalities of soil, ground cover, and action of tree roots. Each condition, such as "under branches," "between branches," and "no brush," or control, was represented by two sampling points. Since natural conditions on the 1919 plots were more or less disturbed by moving branches, digging, and trampling, new plots were established in 1920. On the whole, the scattering was somewhat lighter on the 1920 plots, and they were closer to growing trees, the distance being about 60 feet for the 1919 and 50 feet for the 1920 plots. In both instances the herbaceous vegetation was closely cropped by cattle. In this respect conditions were very different from the 1909 and 1912 series, which were on ground protected against all grazing. Another difference is in the soil. The 1919 and 1920 series were on the loamy clay soil characteristic of the greater portion of the yellow pine type on the Coconino and Tusayan Forests. The 1909 and 1912 series were on a soil which differs from the above in that it contains considerable quantities of cinders in mixture or sometimes forming a thin surface layer.

As in the 1909 and 1912 series, the data point to a saving of soil moisture by the brush cover. (See Table 24 and Figs. 13 and 14.) In 1919 the continued heavy rainfall vitiated the results, so far as critical points are concerned; nevertheless, there was more moisture both under and between branches than in the open in June and September, the only times at which there was even a suggestion of drought. In 1920, the month of June and the first half of July provided a real test by giving values below wilting coefficient at a depth of 6 inches. The points during this period, June 19, July 6, and July 13, show some irregularity, and on the whole there seems to be no more or even less moisture under the brush than elsewhere. This disagreement may be partly explained by the fact that the cover in 1920 was lighter than in any of the previous years, and therefore less effective. The large irregularities in the 12-inch series

are thought to be due to unequal distribution of tree roots. Herbaceous vegetation is believed to have been a relatively unimportant factor, because it was sparse and closely cropped by cattle.

A survey of all the soil-moisture data shows a fairly consistent superiority of brush-covered over uncovered ground during dry periods. Against this stands the fact that only in a single instance, namely, the 1914 experiment previously described, has a brush cover proved a really effective aid to reproduction. This discrepancy is in a considerable measure explained by the fact that seedlings can not grow directly under a dense mat of brush, where the greatest benefits in the way of moisture conservation are secured. Seedlings can grow only under a light cover, in the edges of the larger brush masses, or in openings between branches. Even these situations afford considerable protection against water loss; but, as will be shown later, the seedlings may be forced to yield these benefits to older and more aggressive plants.

TABLE 24.—*Available soil moisture (percentage of dry weight), brush experiment, Fort Valley, 1919–20.*

	1919.										1920.			
	June 6.		June 30.		Aug. 2.		Aug. 30.		Sept. 15.		May 17.		June 4.	
	2 to 3 inches.	6 inches.	2 to 3 inches.	6 inches.	2 to 3 inches.	6 inches.	2 to 3 inches.	6 inches.	2 to 3 inches.	6 inches.	6 inches.	12 inches.	6 inches.	12 inches.
No brush	6.2	10.8	−1.2	0.6	22.8	15.6	7.8	6.0	3.2	2.9	7.0	9.2	4.5	8.3
Between branches	12.3	10.4	−1.0	4.5	22.4	18.2	12.2	7.6	17.3	11.7	6.1	6.6	3.9	4.7
Under branches	15.8	12.3	−0.9	3.4	21.5	15.4	12.9	7.6	.....	.....	6.8	7.9	6.0	7.0
Under litter	17.7	11.9	−0.1	2.0	.....	.....	13.7	9.2	.....	.....	.....	.....	.....	.....
North edge of brush pile	18.6	14.8	6.1	3.9	.....	.....	18.4	14.2	.....	.....	.....	.....	.....	.....

	1920.											
	June 19.		July 6.		July 13.		Aug. 9.		Sept. 3.		Oct. 6.	
	6 inches.	12 inches.	6 inches.	12 inches.	6 inches.	12 inches.	6 inches.	12 inches.	6 inches.	12 inches.	6 inches.	12 inches.
No brush	1.8	5.0	0.0	2.9	[1]−0.2	7.0	6.4	4.1	0.1	.....	0.6	5.0
Between branches	2.4	2.0	−0.6	5.7	−0.6	3.9	7.9	3.9	4.0	2.7	0.9	2.3
Under branches	1.8	2.1	1.0	2.9	0.6	2.0	9.0	3.4	6.8	4.3	1.9	4.7

Wilting coefficient:	Per cent.
1919. Depth, 2 to 3 inches	7.8
Depth, 6 inches	11.3
1920. Depth, 6 inches	13.1
Depth, 12 inches	15.4

[1] Interpolated July 13.

ESTABLISHMENT OF SEEDLINGS IN BRUSH AND NO BRUSH.

It has remained for studies conducted in 1920 to explain the differences betwen the results obtained in the 1908 experiment and

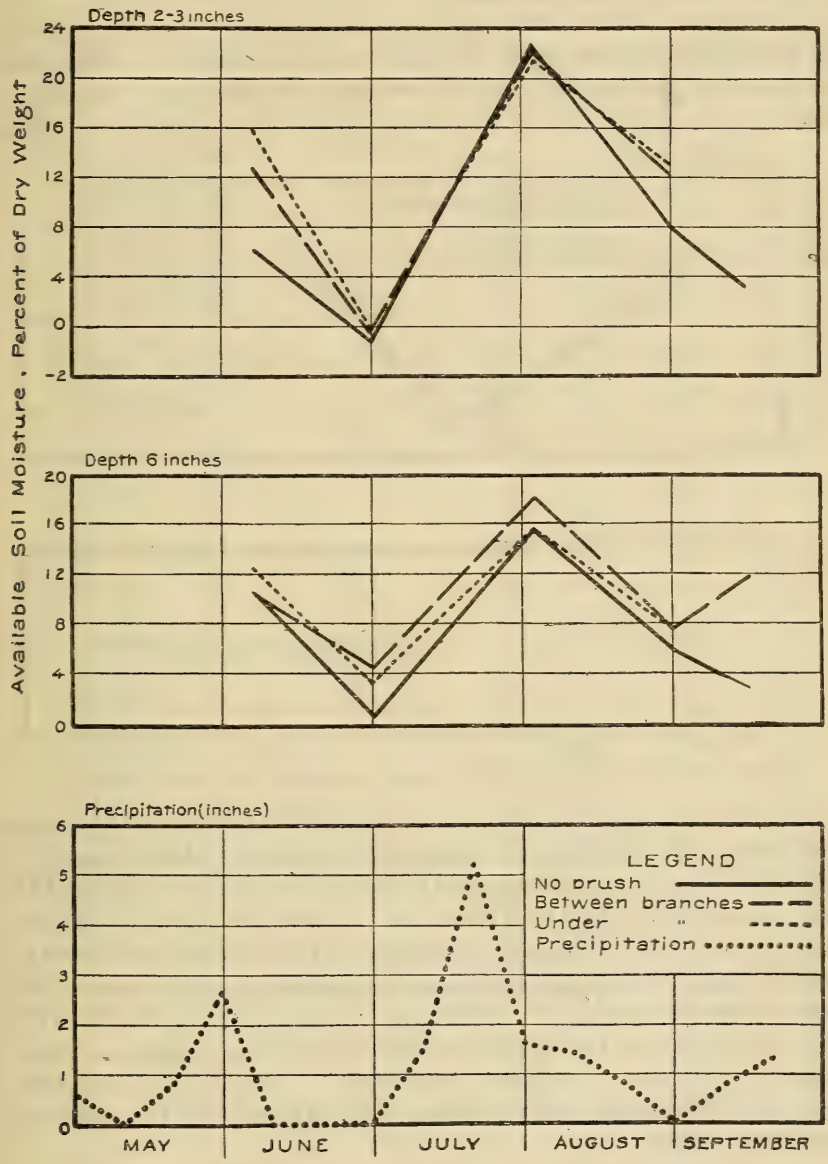


FIG. 13.—Available soil moisture, brush experiment, Fort Valley, 1919.

the 1914 experiment, and, in fact, to clear up the whole problem. The extraordinary seedling crop of 1919 provided unequaled opportunities for this investigation by furnishing abundant material

for study under a great variety of conditions. At the same time an average drought through June and the first half of July, 1920, resulted in heavy thinning, thus bringing about the desired differentiation between various sites.

The results of the 1920 seedling counts under different methods of brush disposal are given in Table 25 and Figure 14. With the exception of groups 6, 7, and 8, seedlings are strikingly less abundant in brush than in open places. These three groups of plots

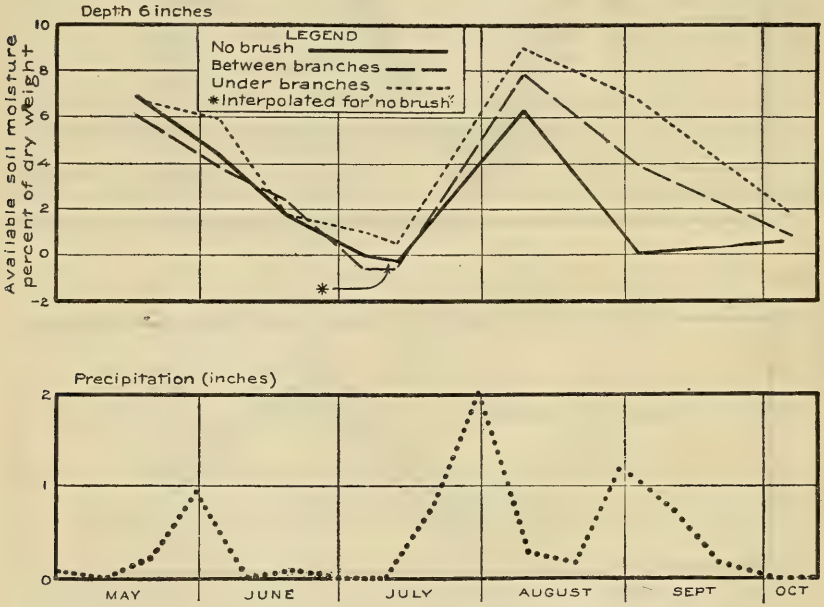


FIG. 14.—Available soil moisture, brush experiment, Fort Valley, 1920.

are on closely grazed or overgrazed areas. Under prevailing range conditions, the herbaceous vegetation, especially bunch grass, is taller and more luxuriant among tree tops (Pls. XVI, Fig. 2, XVIII, Fig. 2, and XIX, Fig. 1), in the edges of brush piles, and in scattered brush than in open places. Exceptions to this rule occur where the ground cover was largely destroyed by grazing or other causes during or prior to logging, as in Groups 6, 7, and 8, Table 25 (Pl. XVI, Fig. 1), or where the branches fell in such deep masses as completely to kill out the original vegetation. Even in the latter case, however, the grasses often develop very strongly in the edges of the brush cover.

TABLE 25.—*Seedling survival in relation to method of brush disposal.*

A. EXAMINATIONS IN SEPTEMBER AND OCTOBER, 1920.

	Basis.	1919 seedlings.			Old seedlings, 4 to 10 years.
		Number per acre.	Large.	Injured or killed by grazing.	
1. Sample plot 3A; logged 1909; heavy bunch grass:					
Inside fence, ungrazed—	*Sq. feet.*		*Per cent.*	*Per cent.*	
Natural areas	400	15,000	14	0	1
Edge brush piles [1]	470	3,180	3	0	1
Burned brush piles	225	30,500	30	0	1
Tops (windfalls)	264	5,200	3	0	0
Outside fence, grazed—					
Natural areas	800	12,200	7	23	1
Edge brush piles [1]	477	13,100	51	40	2
Burned brush piles	286	31,800	26	21	1
Tops (windfalls 1915)	471	4,400	29	4	3
2. Sample plot 3B; logged 1909; heavy bunch grass:					
Inside fence, ungrazed—					
Natural areas	400	8,300	18	0	3
Edge brush piles [1]	600	2,700	20	0	0
Burned brush piles	336	30,500	24	0	0
Tops (windfalls 1915)	192	6,500	0	0	0
Outside fence, grazed—					
Natural areas	200	24,400	.....	21	.....
Edge brush piles [1]	314	10,000	7	([2])	.....
3. S. & M. Co. sale, sec. 6, T. 22 N., R. 6 E.; logged about 1911; bunch grass closely grazed:					
Natural areas	400	17,400	22	52	0
Burned brush piles	229	30,500	42	43	2
Pulled tops	400	7,900	32	1	3
Stump patches	560	12,200	37	41	0
4. McGonigle Co. sale, north of Riordan; logged 1917–18; bunch grass, closely grazed:					
Natural areas	260	8,700	13	35	1
Pulled tops—					
On bare ground	100	11,200	71	7	1
In grass	200	3,200	21	0	7
5. S. & M. Co. sale area; cutting about 1915; heavy bunch grass, lightly grazed:					
Natural areas	320	2,800	0	0	0
Lopped brush	320	1,200	0	0	0
6. S. & M. Co., private cutting, 1910; overgrazed; sparse vegetation:					
Natural areas	320	7,800	70	37	.....
Lopped brush	640	10,100	58	14	.....
Natural areas	260	1,100	33	33	.....
Pulled tops	260	2,200	38	0	.....
7. Section 21, Fort Valley; private cutting; 25 years old; overgrazed; sparse vegetation:					
Natural areas	960	2,200	67	25	.....
Near decayed tops; sparse vegetation	960	2,600	83	17	.....
8. Section 22, Fort Valley; virgin stand; moderate herbaceous cover; closely grazed:					
Natural areas	300	21,000	38	8	.....
Tops (windfalls 1915)	288	6,000	45	0	.....
Natural areas	200	23,600	30	10	.....
Scattered brush	200	36,100	35	1	.....

[1] Counts made in strip, 1 foot wide in periphery of pile. [2] No data.

TABLE 25.—*Seedling survival in relation to method of brush disposal*—Continued.

B. EXAMINATIONS IN OCTOBER, 1921.

	Basis.	1919 seedlings.		
		Number per acre.	Large.	Injured by grazing.
2. Sample plot 3B; logged 1909; heavy bunch-grass:				
Inside fence, ungrazed—	*Sq. feet.*		*Per cent.*	*Per cent.*
Natural areas	192	12,000	24	0
Burned brush piles	192	35,000	30	0
Outside fence, grazed [3]—				
Natural areas	300	5,800	27	27
Tops (windfalls, 1915)	300	1,600	18	0
8. Section 22, Fort Valley; virgin stand; moderate herbaceous cover; closely grazed by cattle; few sheep:				
Natural areas	200	13,300	.....	13
Scattered brush	200	21,800	.....	9
Natural areas	.....	22,300	20	5
Tops (windfalls, 1915)	.....	4,200	29	0
9. Sample plots 5 II and III; logged 1913; grass variable; fenced; grazed by horses only:				
Natural areas, bunch-grass	560	1,440	11	6
Pulled tops, bunch-grass	660	530	0	0
Natural areas, bare [4]	660	0	0	.....
Pulled tops, bare [4]	660	1,520	[5] 83	0
Scattered brush, bare [4]	520	1,090	[5] 100	0
Natural areas, bunch-grass	640	3,370	14	10
Scattered brush, bunch-grass	640	1,120	12	0
Natural areas, bunch-grass	410	740	14	0
Burned brush piles	410	1,590	33	0

[3] At least 25 per cent estimated killed by grazing on natural areas, but none in tops.
[4] Overgrazed clay flat.
[5] Most of these are of extraordinarily large size.

After the first plots revealed the general trend of the data, a second examination showed that invariably, where seedlings were much less numerous in the brush, the grass was taller and more luxuriant in the brush than in the open, and that where the seedlings were equally or more numerous in the brush, it was invariably on areas on which the ground cover was sparse, because of overgrazing or some other abnormal condition. The explanation is simple. Seedlings thrive best where they are not forced to compete with other vegetation. Brush interferes more or less with grazing. It also favors growth by checking evaporation and, in some cases, by adding organic matter to the soil. These benefits, however, the older and more aggressive grasses and weeds are able to take advantage of more fully than young pine seedlings. Consequently, the pine seedlings growing in brush must meet more severe competition than those growing in the open where the herbaceous vegetation is kept down by grazing. But where the natural ground cover had been killed out prior to the placing of brush, as on severely overgrazed areas, roads, and stump patches, the pine seedlings have practically no competition. The relation with respect to number of seedlings also applies to size; that is, the smallest seedlings occur in brush where the grass is unchecked, and the largest occur in brush where there is no grass or other competing vegetation.

The above observations agree closely with those pointed out in the chapters on herbaceous vegetation and cutting. There it was found that the seedlings were much larger on stump patches than elsewhere, providing the herbaceous vegetation was grazed down, but that if this vegetation was unchecked it became so luxuriant that the seedlings were far below normal in both size and number.

The apparent contradiction between results in the 1908 and the 1913 experiments is now readily explained. It will be recalled that in the former case brush-covered patches show slightly poorer restocking than those on which no brush was scattered, whereas in the latter the brush-covered patches show a decided superiority over the open patches. The difference is accounted for by ground cover. In the 1908 experiment the ground cover, in which rank bunch grasses predominated, was practically undisturbed, but in the 1913 experiment it was almost completely eliminated by plowing. In the light of the knowledge gained in 1920, it is evident that if the natural vegetation had not been destroyed in the 1913 experiment, the results would have been similar to those obtained in the earlier experiment.

Table 25 and Figure 15 also show considerably less grazing damage to seedlings in brush than in the open. In fact, practically no damage to the 1919 seedling crop has occurred in the brush up to the end of the year 1921, but in the open spaces an average of from 23 to 50 per cent, and in extreme cases 90 per cent, of the seedlings have been recorded as killed or severely injured. On closely or overgrazed areas with no brush cover the damage often approaches complete destruction. This explains why reproduction in advanced stages is commonly more abundant along old fallen trees than elsewhere. In open situations exposed to excessive grazing, practically every seedling is destroyed, but under the protection afforded by the projecting branches of fallen trees a few seedlings have struggled through, despite the handicap of competition with grasses. On areas of light ground cover this difference becomes all the more striking. Thus it is found that the beneficial effect that brush has been supposed to bring about is limited mainly to protection against damage by grazing. This protection, however, is only temporary and does not obviate the necessity for grazing control.

The question naturally arises, "Are the detrimental effects charged against brush and the favorable effects credited to burning permanent or only temporary?" An absolute answer to this question can be given only after observations have continued over a long period of years. It should be borne in mind, however, that the 1920 data used in Table 25 were secured at the close of the second season or after the period of highest mortality was past (Fig. 16). Examinations at the end of the third season, October, 1921, show no

appreciable change. The seedling counts in 1921 were not made on the same plots as those of 1920, because the 1920 plots were not marked, and for the additional reason that on most of the 1920 plots damage by grazing in 1921 was so evident as to render the plots valueless for the purpose of this study. The fact that the 1921

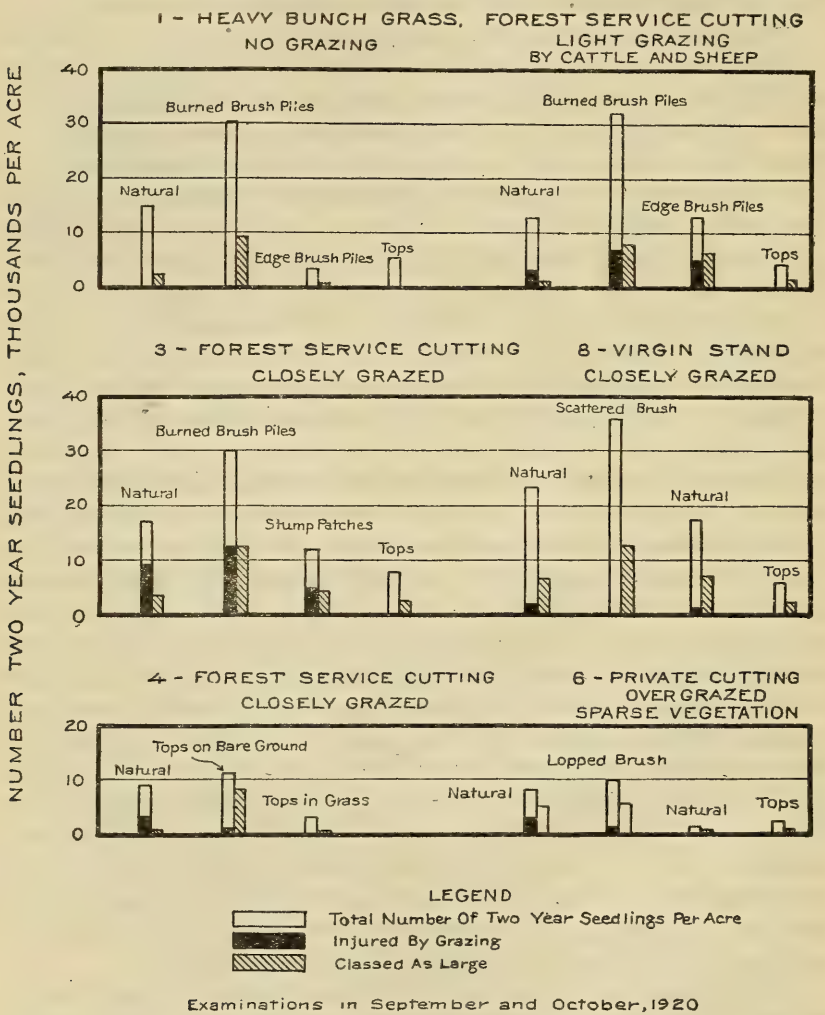


FIG. 15.—Brush disposal and grazing in relation to seedling survival.

data, which were secured on different plots and in some cases in new localities, show substantially the same thing as the 1920 counts, leaves little room for doubt as to either the representative character or the stability of the indicated relationships.

Group 9 was not included in the 1920 counts, because the seedlings on these areas were considered too few to yield decisive conclusions.

Although the stand of 1919 seedlings was scarcely more than one-tenth as dense as that on similar cuttings in the other groups, the present ratio between brush-covered and open areas is practically the same in all cases. Group 9 has produced especially convincing

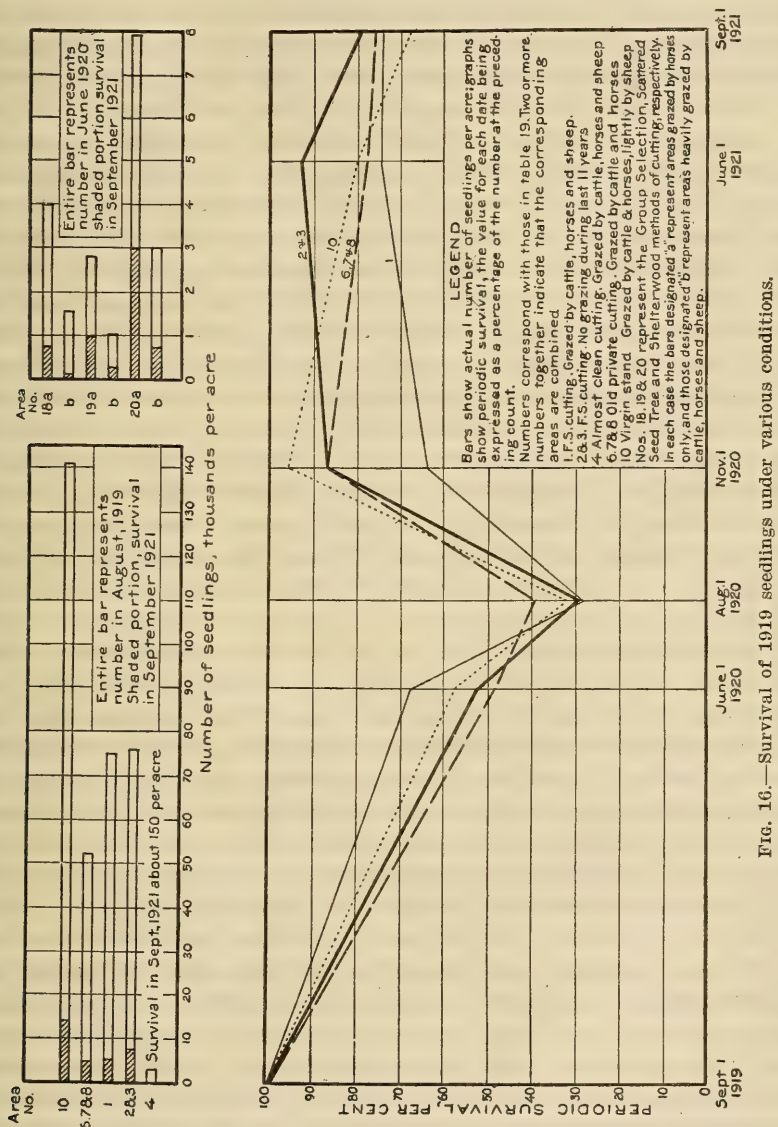


FIG. 16.—Survival of 1919 seedlings under various conditions.

data in regard to the influence of herbaceous vegetation in determining whether brush is beneficial or detrimental to reproduction. Wherever bunch grass is present, even in a thin stand, pine seedlings are invariably less numerous and of smaller size in the brush than where there is no brush. But where the bunch grasses or

other vigorous herbs are absent, the relation is often reversed. This is very strikingly demonstrated by the clay flats or valleys of the sample plots in Group 9. On most of these sites the original bunch grasses have been exterminated by continued overgrazing and packing of the soil. During the summer rains a low annual known as six-weeks' grass (*Sporobolus ramulosus*) springs up, but it quickly disappears and leaves the ground bare, save for occasional clumps of weeds. It has been shown under "Herbaceous vegetation" that on such sites pine seedlings exhibit a distinct preference for clumps of weeds, and it was further pointed out that any kind of dead soil cover, if not too deep, would favor the establishment of seedlings. On the sample plots in Group 9 these sites are apparently devoid of pine reproduction of all ages. Close examination, however, shows that where tops or scattered brush occur, 3-year-old seedlings of splendid development are fairly numerous, whereas on adjacent brush-free areas seedlings are rare and usually of poor development.

Some apprehension was felt regarding the survival of seedlings in burned brush piles, because of the usual absence of shelter or soil cover. The examinations made in October, 1921, completely dispel this fear, because not only are the seedlings from two to three times as numerous as on adjoining grassy areas, but they are noticeably larger and more thrifty. From the standpoint of size, the seedlings in burned brush piles are second only to those in stump patches.

Conditions under which burning is desirable.—Since brush, when associated with luxuriant herbaceous vegetation, has been shown to be detrimental to reproduction, the course which suggests itself as most logical under such conditions is to burn it. A further argument for this method lies in the fact that burning actually improves the conditions for reproduction, as shown by the fact that in the spaces where brush piles have been burned the seedlings are usually larger and two or three times more numerous than on natural grassy areas. This condition is accounted for mainly by the fact that the burned spots, usually from 10 to 12 feet in diameter, are almost bare of herbaceous vegetation and remain so for more than 10 years after the fire, even where there is no grazing. The ground area occupied by brush piles on a Forest Service cutting usually does not exceed 3 or 4 per cent of the total, but in burning the cleared space may be increased to about 6 per cent. The percentage can be materially increased by spreading the piles out more than has been the custom in the past. The extent to which this practice could be carried would be limited by the need for concentration in order to prevent injury to living trees and young growth.

No studies have been made to ascertain whether the burning of brush piles is attended by any important effects other than the destruction of vegetation. It is reasonable to expect an increase of soil moisture as a result of stopping the root action of grasses and other plants killed by the fire. In the surface layers, however, direct evaporation may decrease the moisture content on bare ground. Burned brush piles and other bare spots during temporary droughts in 1920 showed a perceptible excess of moisture, especially at 12 inches, when compared with adjoining areas occupied by a full stand of bunch grass (Table 26). This increase may not always be realized however, because the roots of surrounding vegetation, particularly trees, develop rapidly in the bare spots and soon use up any surplus moisture. Instances have been observed where the spots left by burned brush piles were completely occupied by roots from trees 50 feet distant. Other factors of possible importance are sterilization of the soil and addition of mineral salts found in the ashes. Hesselman (*10*) has found that in northern Sweden burning stimulates nitrification of "raw humus" and thus greatly favors reproduction of Scotch pine. In view of the practical absence of organic matter in our soils, however, it is improbable that nitrification is a factor to be reckoned with. Cases have been observed where the surface soil appeared to have been injured by burning. This can be avoided by limiting the size of piles. It is a curious fact that pine seedlings should thrive in these burned spots which other vegetation invades so slowly. This and other questions afford a good field for further investigation. The important fact in the present stage of the investigation is that burned spots and other areas which are bare of herbaceous vegetation are almost invariably restocking better than grassy areas. Exceptions to this rule may occur where the destruction of herbaceous vegetation has been accompanied by packing. The burning of brush piles on such areas can not be expected to improve moisture conditions through the elimination of plant roots. If the soil happens to be a stiff clay, burning may prove positively injurious by consuminig what little surface mold or litter may have been present. All available information points to the desirability of leaving the brush on bare sites, particularly if the soil is clayey or if the gradient is such as to encourage erosion.

Reference is frequently made to the benefits supposed to accrue from the decomposition of brush and the incorporation of this organic matter in the soil. Light or moderate applications of brush, as in scattering, produce negligible quantities of humus. As has already been pointed out, however, the semidecayed litter resulting from scattered brush aids germination on bare ground. Large accumulations of brush, as in pulled tops or where piles

have been left unburned, when rotted down leave an inch or more of mold on the surface of the soil and give a dark color to the soil to a depth of 2 to 3 inches. This stage of composition is not reached until from 15 to 20 years have elapsed. If herbaceous vegetation is kept down by grazing, these spots favor the establishment and rapid growth of seedlings. As a means of permanently increasing the humus content of the soil, however, brush is ineffective, because it reaches only the surface layers, where the nitrates resulting from decomposition are rapidly dissipated by the dry atmosphere. The greatest objection to deep layers of brush, aside from the fire danger, is that during the first 15 or 20 years after cutting, which is the normal reproduction period, they hinder rather than favor reproduction.

TABLE 26.—*Relation of brush and ground cover to soil moisture, 1920.*

Location.	Wilting coefficient. at—		Available soil moisture at—	
	6 inches.	12 inches.	6 inches.	12 inches.
			Per cent.	*Per cent.*
Fort Valley, July 9:				
Tall grass	13.1	15.4	−1.0	−1.2
Sparse vegetation			1.7	4.6
Fort Valley, Oct. 6:				
Tall grass	13.1	15.4	−0.4	3.1
Sparse vegetation			0.6	5.2
Tree top—				
Litter 2 to 3 inches [1]			2.4	3.0
Between branches, grass			2.7	0.9
Sample plot 3, Oct. 9:				
Tall grass	10.7	11.9	−0.7	0.1
Burned brush piles [2]			−0.3	1.5

[1] Mat of needles about 2 feet in diameter; grass in edges.
[2] Sparse vegetation, but soil permeated by network of roots from group of trees 50 feet distant.

The foregoing data lead to the general deduction that on areas bearing a dense, luxuriant growth of herbaceous vegetation, especially tall grasses, brush in any form is detrimental to pine reproduction; but that on clay soils, if the herbaceous cover is light or can be held in check by grazing, brush cover is beneficial. On steep slopes control of erosion may be an additional reason for leaving the brush. Assuming, therefore, that under certain conditions it is more desirable to leave the brush than to burn it, we should know something of the relative advantages of the methods which do not involve burning.

Comparison of scattering, pulling tops, and lopping.—Data giving a direct comparison between scattering, pulling tops, and lopping are not so complete as could be desired. Scattering has not been practiced to any appreciable extent on the Coconino and Tusayan National Forests [19] and has rarely been executed in accordance

[19] The standard practice on the Coconino and Tusayan is pulling tops, except on fire lines or in places of great fire danger, where piling and burning is practiced.

with the principles formulated by recent investigations. Only on rare occasions do two of the methods occur side by side under comparable conditions. Lopping, though here distinguished from pulling, is but a by-product of the latter method. The conditions created are exceedingly variable, sometimes approaching pulled tops and sometimes scattering. No serious effort has been made to determine the merits of lopping in comparison with the other two methods.

In the 1920 counts of Table 25, only Groups 6 and 8 contain data on lopping and scattering. These methods are not directly comparable with each other or with pulling, because they were applied under varying conditions, and therefore the only means of comparison is through the medium of parallel control plots on natural areas. In Group 6, both lopping and pulling excel the natural or non-brush-covered plots. This is due to the fact that practically no herbaceous vegetation occurs either in the brush or in the open, and thus the seedlings derive the full benefit of the favorable influences of the brush. As a general rule, under such conditions, the seedlings in the brush are larger than those outside; but in the case of lopping, the relation is reversed in this particular instance. In point of numbers the difference between lopping and pulling, when compared with the respective control plots, is not sufficient to justify any conclusions. In Group 8 scattering shows a distinct superiority over pulling. In this case the grass was closely grazed on the open areas and in the scattered brush, but it was scarcely touched in the tops.

The counts made in 1921 furnish a better comparison, although, as in 1920, it was not always feasible to compare the various methods directly. In Group 8 the superiority of scattered brush over pulled tops is demonstrated even more strikingly than in 1920. In this instance the scattering and corresponding controls are represented by the same plots in 1920 and 1921, but in the case of pulling new plots were selected in order to secure more typical conditions. In Group 9 pulling appears to have a small margin over scattering on the bare areas, but on grassy areas there is no pronounced difference.

In the absence of sufficient data for a direct comparison, the best means of approaching a decision as to the relative merits of the scattering, pulling, and lopping is to consider the physical conditions attainable under each method.

Pulling tops creates exceedingly variable conditions. Where the crown is dense, the mass of branches and needles effectively bars the entrance of pine seedlings for at least 10 years. Where the crown is open, the surface of the ground is but little affected. Often both extremes are encountered in different parts of the same top. Usually

it is only in occasional spots that conditions are such as to permit the establishment of seedlings. One of the greatest difficulties of the method is that it can not be properly controlled.

Lopping, as practiced in connection with pulling, creates variable conditions which can best be described as intermediate between pulling and scattering. It is subject to the same lack of control and has practically all the other disadvantages of pulling.

In scattering it is possible to secure much more uniform conditions than in pulling and lopping. Since almost every branch must be handled in scattering, the density and distribution can be so regulated as to permit access by grazing animals, thus preventing a rank growth of grass and weeds. Observations indicate that the best results can be secured by placing the brush in small, dense patches two or three branches deep, separated by open spaces from 2 to 3 feet wide. The dense mat of brush will kill out the grass directly underneath it, and the luxuriant growth in the edges can be kept down by cattle grazing. Few seedlings will gain a foothold directly in the patches of brush, but some will become established in the edges, where they will benefit from the surplus moisture conserved underneath the brush. All available information indicates that if the above principles are applied this method will give better reproduction than pulling or lopping. Scattering is not recommended for bunch-grass lands, however, unless there is absolute assurance of proper coordination with grazing.

Disposal of brush where reproduction is established before cutting.—One condition which has not been considered in the foregoing discussion is that in which reproduction has taken place in advance of cutting. Under such circumstances the brush should, as a rule, be piled and burned as a precaution against fire. Exceptions may occur on slopes subject to severe erosion. Under these circumstances brush should be piled without burning, pulled, or scattered in roads, skidder trails, and other places where needed to check erosion. Until recently some apprehension has been felt as to the possibility of burning without excessive damage in dense reproduction. Experience during the past year indicates that, although great care must be exercised, it is usually possible to burn with comparatively little damage.

If advance reproduction is below a foot in height, many seedlings are likely to be entirely covered with brush. Instances have been observed in which fully 75 per cent were killed on spots where brush was scattered. Pulling tops and lopping are even more disastrous on the immediate patches occupied.

GRAZING.

REVIEW OF PREVIOUS INVESTIGATIONS.

As early as 1904, Leiberg (*14*) expressed his conviction that sheep grazing is responsible for the failure of western yellow pine reproduction in the San Francisco Mountains.

Investigations by the writer (*15*) on the Coconino National Forest in 1908 showed that the number of seedlings browsed under average grazing conditions ranged from 10 to 41 per cent for the current season, while on sheep driveways and bed grounds the percentage was considerably higher. This damage was attributed almost wholly to sheep, and therefore it was recommended that sheep be excluded from cutting areas on which reproduction was deficient during a period of 20 years, which was the estimated average time required for reproduction to become established and grow beyond serious danger of injury from sheep.

The above study was continued on a more extensive scale by the Fort Valley Experiment Station in 1910. This investigation supported the conclusions arrived at in 1908, but also pointed out the need for more detailed consideration of damage under various conditions prevailing on the range, with the object of ascertaining the effect of such factors as abundance and character of forage, intensity of grazing, and season of grazing. Accordingly a more comprehensive working plan was developed, and the project was assigned to Grazing Examiner Hill, under the direction of the Office of Grazing. Hill pursued the investigation vigorously during the years 1912, 1913, and 1914. He made from four to five examinations annually on 250 plots, distributed over a radius of 25 miles about Flagstaff. The following is a summary of his findings (*11*):

Out of 8,945 trees of a size subject to grazing injury 16.7 per cent were severely damaged and 16.1 per cent moderately damaged each year. For seedlings below 6 inches in height the number seriously injured amounted to 21 per cent. These figures refer to current damage. Hill's work, as well as that of Chapman, Westveld, Kimball, and the author, shows that the cumulative effect of such damage over a long period of years may nullify all progress in reproduction.

The average amount of damage per week during various seasons was as follows: April 15 to May 20, 0.07 per cent; May 21 to July 8, 2.5 per cent; July 9 to September 12, 1.9 per cent; September 13 to November 6, 0.9 per cent. From these figures it appears the amount of damage prior to May 20 was negligible. The greatest damage occurred during the latter part of June and early in July, or during the dry foresummer. Contrary to prevailing opinions, the damage

occurring during the summer rainy season, when forage is at its best, is considerable. During the fall months the damage falls off appreciably, but is still important.

On overgrazed range open to all classes of stock 35 per cent of the seedlings were severely injured annually, as against 11 per cent on range which was grazed normally.

Palatability of forage is an important factor. The coarse bunch grass, *Festuca arizonica*, which predominates on what is known as the bunch-grass type, is little relished by any stock and is particularly ill adapted for sheep feed. In 1912 and 1913, 32 per cent of the seedlings were injured on this type of range when grazed by both sheep and cattle, and considerable numbers were found to have been actually killed. Much less damage occurs when the forage is made up largely of more palatable plants, such as grama grass and succulent weeds. About one-third of the bunch-grass type, aggregating 130,000 acres on the Coconino, is classed by Hill as suffering from excessive damage by grazing.

Sheep are responsible, on the average, for about eight times as much damage as cattle. On the bunch-grass range the ratio shows a still wider disparity. Cattle do considerable damage in places where they congregate, especially if confined and underfed. On the whole, however, the damage by cattle and horses is not sufficient to cause serious concern.

The following is quoted from Hill's recommendations:

1. Since overgrazing is the cause of the most severe grazing damage it should be avoided by all means. An overgrazed condition may exist even though the general appearance of the range does not indicate it, as, for instance, on a bunch-grass range allotted to sheep. The principal grasses may be largely uneaten, while sheep feed, consisting of palatable weeds and grasses, and, too often, of yellow-pine reproduction, may be largely destroyed. Overgrazing may result from allotting too many stock to a range, or from poor distribution of a proper number of stock due to lack of sufficient well-located watering places, poor salting arrangements, or, in the case of sheep, to poor herding. In any case the cause should be determined and removed.

2. Sheep should not be depended upon primarily to utilize the bunch-grass range. This type should be utilized chiefly by cattle and horses, held in pastures if possible. On this type, wherever the bunch-grass species occur in nearly pure stand during early spring, sheep should be run in May and the fore part of June while the grasses are tender and most palatable. Where the succulent weeds and browse species occur in mixture with the bunch grasses, sheep may be grazed season-long together with cattle and horses.

3. Sheep should be excluded from cutting areas on which they are causing severe damage until reproduction is well established, usually for a period of from 15 to 20 years. They should be excluded also for a period of from two to five years from cutting areas where the stand of reproduction is deficient but has been supplemented by an abundant crop of seedlings which, having survived the first winter and spring, promise to become established, even though injury to the reproduction already established is not severe.

Gregory (*5*) quotes the following from notes on the Navajo and Hopi Indian Reservations by G. A. Glutches, supervisor of forests, U. S. Indian Service:

> The reproduction of yellow pine over the yellow-pine type is very poor and scattered. For the most part the reproduction can be considered as nil. This is due to sheep and goat grazing. There are no signs of reproduction on the cutover areas about the Navajo and San Juan Agency Mills.

During the years 1918 and 1919 Assistant District Forester H. H. Chapman made both intensive and extensive examinations on the National Forests of Arizona and New Mexico. His observations are valuable because of their extensive character and because his investigations are independent of those previously made. A large part of Chapman's work consists of comparisons between the reproduction on areas open to sheep as well as to cattle and horses and that on fenced areas from which sheep have been excluded. One method of investigation which had been neglected in former work, but which has been successfully employed by Chapman, is that of searching out the more or less obscure grazing history of various sections of the range. By this means he has established in a number of instances that certain areas which supposedly have been heavily grazed by sheep over long periods of years, have in reality not been heavily grazed, or have been only periodically grazed by sheep. Numerous unpublished reports and memoranda by Chapman show that he regarded sheep grazing as the primary cause for failure of western yellow-pine reproduction on the Colorado Plateau.

An extensive survey by Westveld and Kimball on the Coconino and Tusayan Forests in 1919 to determine areas in need of protection from grazing in order to insure adequate reproduction, showed that the average amount of serious damage on sheep range was 33 per cent for seedlings between 2 years of age and 6 inches in height and 21 per cent for those between 6 inches and 3 feet. The number of seedlings below 3 feet in height averaged two and a half times as great on areas from which sheep were excluded as on those grazed by sheep together with other stock.

INVESTIGATIONS OF 1919–1921.

EXAMPLES OF DAMAGE BY SHEEP GRAZING.

One of the simplest ways of securing concrete evidence of the effect of sheep grazing upon reproduction is by comparing inclosed areas grazed only by cattle and horses with surrounding areas grazed also by sheep. Small pastures established by homesteaders in different parts of the forest furnish numerous opportunities for such comparisons. Almost invariably where an area has been fenced against sheep 10 years or more it shows strikingly better

reproduction than the area outside which has been open to sheep. Very often reproduction outside is a total failure, while inside it is a partial if not a complete success. A typical example of this kind is furnished by two pastures belonging to W. H. Taylor and C. H. Corey, near the Fort Valley Experiment Station. The results of examinations of these areas in 1918 and 1920 are given below.

The Taylor pasture, the greater portion of the Corey pasture, and the adjoining open range are covered by a virgin stand of yellow pine. Although considerable portions of the area are too heavily shaded for good reproduction there are numerous openings sufficiently large to permit excellent seedling development. A portion of the Corey pasture is on the border line between the forest and the adjoining open valley. The soil is a gravelly loam deposited at the mouth of a canyon which debouches about 1,000 feet up the slope of the San Francisco Mountains. This soil is classed as one of the most favorable soils for reproduction in this region. Herbaceous vegetation is mainly of the weed type. A good seed crop occurred in this locality in 1913. Light crops occurred in 1915 and 1916. In the summer of 1914, which was unusually favorable for germination and survival, pine seedlings appeared in great numbers. Four years later dense groups of seedlings from 4 to 8 inches in height were in evidence all over the Taylor pasture, which was fenced in the fall of 1913. They were far less conspicuous on the adjoining open range and in the Corey pasture, which was not fenced until the spring of 1916.

On August 15, 1918, a number of plots were established along the east fence of the Taylor pasture, separating the pasture from the open range. Here the trees are so grouped as to form a series of openings 40 to 60 yards wide by about 100 yards long, with the major axis almost perpendicular to the fence. In two of these openings seedling counts were made on strips extending about 40 yards on either side of the fence. In laying out the strips care was exercised to locate them so that the sections inside and outside of the pasture would be similarly situated with reference to seed trees. In each case the strips run roughly parallel to and about 50 feet distance from the south edge of an opening whose major axis extends nearly east and west. The strips occupy a zone which represents the densest seedling growth. On July 31, 1920, the same plots were examined again.

Table 27 gives the results of the 1918 and 1920 examinations. Although three age classes (1914, 1916, and 1917) are represented, the 1914 class is by far the most prominent, both as to number and size. Only a few of the 1917 class were in evidence in 1918, and on account of the dense growth of lupine no serious effort was made to

count them, they being then only in their second year. It is evident, however, that a considerable number of these small seedlings must have survived, since the total number of all age classes is slightly greater in 1920 than shown by the 1918 counts. No seedlings originated in 1918, since absolutely no seed was borne in 1917. Seedlings from 1919 germination were fairly abundant but were not counted.

TABLE 27.—*Damage to reproduction by sheep on a favorable site.*

[Pastures grazed by cattle and horses only. Open range grazed also by sheep. Seedlings of 1914, 1916, and 1917 germination.]

Location.	Dimensions.	Number of seedlings.		Average height.	
		1918	1920	1918	1920
	Feet.			*Inches.*	*Inches.*
Taylor pasture	8.5 by 118	234	288	6.6	10.4
Open range	8.5 by 118	101	106	2.5	4.6
Corey pasture	8.5 by 118	86	95	3.4	7.2
Taylor pasture:					
Adjoining fence	8.5 by 60	161	176	.....	13.9
60 feet distant	8.5 by 45	228	256	.....	11.2
Total or average	.....	389	432	8.0	12.6
Open range (outside of Taylor pasture):					
Adjoining fence	8.5 by 60	30	15	.....	3.3
60 feet distant	8.5 by 40	12	14	.....	5.3
Total or average	.....	42	29	2.6	4.3
Corey pasture	10 by 50	.....	17	.....	7.9
Open range	10 by 50	.....	5	.....	2.4

The outstanding feature of Table 27 is the great superiority in both number and size of the seedlings in the Taylor pasture. Since this area was inclosed in the fall of 1913, the large seedling crop which germinated in the summer of 1914 received full protection against sheep. Damage to this crop of seedlings undoubtedly accounts for the smaller number on the open range as well as in the Corey pasture, which was grazed by sheep until the spring of 1916. Since no good seed crop occurred after 1913 (except that of 1918, which is not considered in these counts), the Corey pasture has not been able to gain noticeably on the open range in point of numbers. With respect to height, however, it showed a distinct lead over the open range in both 1918 and 1920. The lower average height in the Corey pasture than in the Taylor pasture is accounted for partly by the stunted growth resulting from injuries prior to 1916, and partly by the fact that many seedlings were killed prior to 1916, thus reducing the number in the oldest age class. It is interesting to note that in both pastures the average height growth from 1918 to 1920 was 4 inches, whereas on the outside it was only 2 inches.

Since both of the above pastures have been closely grazed by cattle and horses, the only conclusion which can be drawn is that the excellent reproduction is due to the exclusion of sheep. It should also be borne in mind that these areas, outside as well as inside the pastures, represent optimum conditions for yellow pine reproduction. The counts still show a fairly good number of seedlings outside the fences, although they are as a rule injured. It is possible that on such sites as this the pine may eventually restock in spite of sheep grazing, as it has evidently done on certain areas in the past. This is by no means certain, however, as indicated by the following examples on the Apache and Sitgreaves National Forests, where conditions in general are more favorable for reproduction than on the Coconino and Tusayan.

A most striking example of the effects of sheep grazing is found on the White Mountain Indian Reservation near Cooley, Ariz. About 8 miles east of Cooley is a drift fence. On the east side sheep have grazed for years. The forest is a heavy virgin stand of yellow pine. Reproduction is scanty, and almost every seedling is badly damaged by sheep. On the west side of the fence sheep have been excluded. The timber, topography, and soil are in no way different from the east side; but immediately on passing through the fence one finds seedlings in considerable numbers, which increase until one-half mile west of the fence the openings between groups of trees are completely stocked with saplings ranging from 3 to 6 feet in height. Evidence shows that sheep have gone through the fence to some extent, thus accounting for the lighter stocking of seedlings near the fence than farther to the west. The fact that the forage here is mainly bunch grass is probably an important factor.

In May, 1919, Chapman noted, regarding the Chevalon district on the Sitgreaves National Forest:

> The conclusion is that the presence of all the reproduction in those portions of the Chevalon District which are reproduced is due to the fact that sheep have not been present to any extent on these areas during the years when the seedlings originated and were growing to a height of three feet—and that reproduction is practically absent on all areas continually grazed by sheep for 30 years, while on areas grazed for a lesser period the age classes are absent which would correspond to the period within which sheep have grazed.

Chapman makes similar observations regarding the Heber district on the Sitgreaves and various parts of the Coconino.

Dozens of examples can be cited which are no less impressive than the ones just described. A partial list of areas in the vicinity of Flagstaff is given in Table 28. In every instance the evidence of destruction by sheep is overwhelming. In some instances, no doubt, the excessive damage outside the fence is due partly to overgrazing by all classes of stock, especially sheep; but grazing has

been even more intense in the pastures which are almost invariably overstocked with cattle and horses.

TABLE 28.—*Areas showing damage by sheep.*

Description of fenced areas.			Condition of reproduction.		Stand of timber, all yellow pine.
Designation.	Years fenced.	Class of grazing.	Inside, no sheep.	Outside, C., H., and S.	
Taylor pasture, Fort Valley	7	C. and H., overgrazed.	Complete	Poor	Virgin.
Corey pasture,[1] Fort Valley	5	do	About two-thirds.	Poor or none.	Virgin and open.
McCoy pasture,[1] Fort Valley	6	do	do	do	Do.
Experiment station pasture	12	Mainly H	About one-half.	Good [2]	Pasture cut over; outside virgin.
Sauer pasture, southwest of Riordan.	7	C. and H., overgrazed.	Complete	Poor	Forest Service cutting.
Atchison, Topeka & Santa Fe right of way, Riordan.	20±	None	Generally good.	do	Forest Service cutting on both sides.
Section 6, north of Riordan	20±	C. and H	Complete	None	Old cuttings.
Experiment area, 8 miles east of Flagstaff.	12	None	About one-half.	Patches	Forest Service cutting.
Sample plots 3A and 3B	11	do	do	None	Do.
Bly Ranger Station	8	Mainly H	Complete	Partial	Virgin.
Walnut Canyon Ranger Station	10	do	Good	Poor	Do.
A. L. & T. pasture, Flagstaff	25±	do	do	Patches	Old cutting.

[1] Corey and McCoy pastures are in edge of a large park. The timbered areas are in most places fully stocked, and reproduction has advanced 100 yards into the open area.
[2] Sheep grazing light and irregular.

One of the less striking examples, but from a scientific standpoint most significant, is that of the fenced sample plots 3A and 3B. These plots lie in the midst of a tract excessively used by sheep and almost wholly devoid of reproduction. It is typical of some 150,000 acres in the bunch-grass type between Flagstaff and Belmont, mainly on the north side of the Santa Fe Railroad. Aside from the 1919 crop of seedlings, which was unusually abundant, young growth occurs outside of the fenced plots only in scattered patches. Careful inspection reveals considerable numbers of seedlings between 4 and 8 inches in height hidden in grass or brush. The few which have grown above the protective covering almost invariably bear evidence of repeated injury by grazing. Often only a few tufts of browsed needles remain, and not infrequently the plant is entirely dead. In the fall of 1919 a seedling survey was made by running a strip 66 feet wide around each plot inside and outside of the fence. In order to avoid abnormal conditions which might result from stock drifting along the fence, the course of the outside strips was kept about 100 feet away from the fence. Only seedlings 1 foot or more in height were counted, since smaller ones could not be seen at a distance on account of the grass. Table 29 shows the number of seedlings in the strips outside the fence, compared with parallel strips of equal width just inside the fence. The seedlings are five times as numerous inside

the fenced plot 3A as outside, and 62 times as numerous inside 3B as outside. Plot 3B shows the relation more truly than plot 3A, because on strip W, outside of plot 3A, 18 of the 24 seedlings occur in one group on a rocky point, where grazing evidently has been below normal intensity. Averaging the two plots, the seedlings are almost 10 times as numerous inside as outside. The comparison becomes even more striking when we consider that over 50 per cent of the seedlings outside the fence are so severely injured that they can not live more than a few years under past grazing conditions.

TABLE 29.—*Damage by sheep in the bunch-grass type.*

[No grazing inside inclosure; grazing by sheep and cattle outside.]

Strip.	Sample plot 3A.			Sample plot 3B.		
	Area.	Number of seedlings 1 foot or more in height, 1918.		Area.	Number of seedlings 1 foot or more in height, 1918.	
		Inside.	Outside.		Inside.	Outside.
	Acres.			*Acres.*		
N	1.0	26	0	1.0	17	0
W	1.2	101	[1] 22	1.2	23	0
S	1.0	39	12	1.0	99	2
E	1.2	4	0	1.2	52	1
Total	4.4	170	34	4.4	191	3
Per acre		38.7	7.7		43.4	0.7

[1] Eighteen of these in one group on rocky point.

Reproduction on adverse sites.—The results on plots 3A and 3B are especially valuable, because they show that even on the bunch-grass lands, which probably are more adverse to reproduction than other extensive areas in the yellow pine type, reproduction can be secured if damage by grazing is eliminated. Because of the almost imperceptible progress on these plots during the first six or seven years after they were established, it was feared that they would not restock even with protection from sheep. If this were the case, the exclusion of sheep from such areas would impose a hardship upon the sheep industry without benefiting the forest. Uncertainty on this question has been responsible, more than anything else, for the delay of sheep control as it is related to injury to yellow pine reproduction in the Southwestern district. But results now show conclusively that reproduction can be secured, and that failure in the past has been due chiefly to sheep grazing.

Damage to first-year seedlings.—One aspect of the problem which has not been adequately treated in former investigations is that of damage to seedlings in their first year. The reason for this is that first-year seedlings are usually not abundant, and, owing to the ex-

tremely heavy losses from natural causes, it has been difficult to get reliable information in regard to the damage by grazing. In the studies prior to 1919, from 95 to 100 per cent of the seedlings on the protected as well as on the unprotected plots died from causes other than grazing; thus, although grazing damage was usually apparent, the number of seedlings left formed an inadequate basis for conclusions. Hill's records for the most part consider only seedlings beyond the first year. He states that except during a succession of unusually favorable summers, nearly all of the first-year seedlings die from causes other than grazing, and therefore a record of damage by grazing would have little significance. While this is true, nevertheless the older seedlings must come from first-year seedlings, and the chances for a crop of first-year seedlings to develop into trees is certainly decreased if a large proportion is destroyed by sheep during the first season. The only published observations on this point are those of Leiberg (*14*), who, on the basis of examinations on the Coconino Forest in 1904, concluded that sheep destroy a very large proportion of the seedlings in their cotyledon stage, but that after they are 3 or 4 years old the damage is relatively slight. The present investigation and that of Hill both indicate that the damage during the cotyledon stage is of less consequence than that which occurs after this stage is passed.

The large seedling crop of 1919 furnished the long awaited opportunity to observe the effect of grazing upon seedlings during their first season. As the seedlings sprang up at the rate of from 10,000 to 200,000 per acre, the number surviving after allowing for normal mortality insured an adequate basis for conclusions. In August, 1919, 46 plots aggregating 4,150 square feet were established along a line beginning 2 miles east and extending 5 miles west of the Fort Valley Experiment Station on range grazed by sheep, cattle, and horses. Forty-four check plots aggregating 2,750 square feet were established within inclosures grazed only by cattle and horses or closed to all grazing. The results are given in Table 30. The number of seedlings injured by grazing on typical sheep range from August to the end of October of the first year varied from 8 to 23 per cent, with an average of 12 per cent for all groups of plots under observation. Whenever a seedling was injured, almost the entire crown was bitten off, killing the plant outright. To a trained observer these decapitated stems are readily visible. At the time the plots were established, right after germination, practically no damage was discernible, excepting in rare instances, as on trails and bedding grounds. It is possible that seedlings in the early stages may be completely destroyed, but after they are 3 or 4 weeks old the roots are not pulled out by cattle or sheep, and therefore

TABLE 30.—*Damage to western yellow pine seedlings by various classes of stock in first, second, and third year after germination.*

	Basis.		Grazing.	Type of range.	Forest.	Number of 1919 seedlings per acre.					Damage by grazing, per cent of total number at time of count.											
	Number of plots.	Square feet.				August, 1919.	June 1, 1920.	November 1, 1920.	May, 1921.	October, 1921.	August, 1919, killed.	October, 1919, killed.	June 1, 1920.		Aug. 15, 1920.		Nov., 1920.		June, 1921.		Oct., 1921.	
													Killed.	Injured.	Killed.	Injured.	Killed.	Injured.	Killed.	Injured.	Killed.	Injured.[4]
East of Fort Valley station:																						
Sample plot 2B, fenced.	7	350	None	Bunch grass and weeds.	Old cutting.	.....	6,700	1,305	1,160	1,015	0	0	0	0	0	0	0	0	0	0	0	0
Open range	3	300	Close C, H, S.	do	Virgin	30,000	21,000	8,000	8,000	7,400	0	8	0	0	0	0	5	9	0	7	0	50
Around Fort Valley station:																						
Sample plot 1B, fenced.	8	400	Close C, H	do	Old cutting.	69,000	37,000	13,400	10,800	7,100	0	0	0	0	0	0	0	0	0	1	1	5
Section 27, fenced	12	1,100	do	do	do	36,000	22,000	3,500	1,360	925	0	0	0	0	0	0	0	0	3	0	0	0
Section 22, open	13	950	do[1]	do	Virgin	141,000	69,000	23,900	18,700	14,200	0	1	0	0	0	0	0	5	0	4	0	10
Section 22, fenced	1	100	None	do	do	125,000	49,000	14,400	12,600	10,900	0	0	0	0	0	0	0	0	0	0	0	4
Section 15, open	3	300	Close C, H, S.	do	do	131,000	62,000	43,400	39,900	34,100	0	8	0	0	0	0	1	7	3	4	2	16
Near Wing Mountain, open.	9	800	Moderate C, H, S.[5]	do	do	145,000	50,000	12,200	7,900	6,400	0	23	0	0	5	3	27	31	5	16	0	31
West of Wing Mountain:																						
Sample plot 3A, fenced.	8	400	None	Dense bunch grass.	Forest Service cutting.	90,000	43,000	12,200	12,100	9,700	0	0	0	0	0	0	0	0	0	0	0	2
Near plot 3A, open	9	900	Moderate C, H, S.[5]	do	do	60,000	41,000	7,300	5,300	3,300	0	5	0	0	22	2	11	16	0	13	3	20
Do	7	700	Overgrazed	Weeds[2]	do	.....	.....	2,000	.....	1,100	.....	.....	.....	.....	11	76	0	73	.....	.....	0	60
Sample plot 3B, fenced.	8	400	None	Dense bunch grass.	do	61,000	37,000	8,200	6,900	4,900	0	0	0	0	0	0	0	0	0	2	0	2
Near plot 3B, open	2	200	Moderate C, H, S.[5]	do	do	130,000	90,000	16,600	12,600	9,400	0	9	0	0	28	6	39	20	2	14	0	23

Sample plot 5, 20 miles south of Flagstaff:							July 1.						July 1, 1920.				Oct. 15, 1920.[3]					
I. (AD) fenced	19	2,150	Light, H	Grasses and weeds, variable.	do		3,940		1,005	730			0	0			0	0	0	5	4	6
(CEFG) open	24	4,470	Overgrazed, C, H, S.		do		1,538		118	118			2	0			50	13	0	17	2	6
II. (BCE) fenced	27	6,150	Light, H		do		2,824		1,005	970			0	0			0	0	0	3	2	11
(ADFG) open	29	6,120	Overgrazed, C, H, S.		do		1,132		300	234			0	0			11	33	0	13	8	23
III. (BCE) fenced	16	3,440	Light, H		do		7,874		3,400	2,990			0	0			1	13	0	4	0	4
(ADFG) open	27	5,460	Overgrazed, C, H, S.		do		2,976		827	742			10	0			24	58	2	7	3	59

[1] Sec. 22 lies within an area excluded to sheep, but they get in to a limited extent.

[2] These plots are on spots formerly occupied by large tree groups. The vegetation is the succulent weed type which is relished by sheep. Seedlings are very large and vigorous, and therefore even the most severely injured were rarely classed as killed.

[3] Only about one-half of the plots were examined on account of snow.

[4] The October, 1921, records include all seedlings which showed appreciable injury and therefore probably include a few which were recorded as injured in the preceding examination.

[5] Areas 8, 10, and 13 are "class overgrazed" by sheep.

the stubs are believed to furnish direct and reliable evidence as to the amount of damage by browsing. (Pl. XXI, Fig. 1.) Regardless of what has been written about the damage by trampling, it is fair to assume that if many seedlings were killed by trampling, the dead plants would be in evidence for two or three weeks after being killed. The writer took special pains to make observations on this point during the summer of 1919. At no time was the damage by trampling conspicuous, excepting where stock had trailed in large numbers, and even on trails the destruction was seldom complete. While seedlings are very tender they may be broken off by trampling, but after they are 3 or 4 weeks old they acquire a wiry character which enables them to resist breakage remarkably well. After the first four weeks most of the damage inflicted by the hoofs of grazing animals is caused by horses or cattle running over soft ground; often under such circumstances seedlings are pressed entirely into the earth. Exhaustive examinations in 1919 confirm the previous conclusion that the damage to seedlings during the first season, both by grazing and by trampling, is relatively small, and that the most serious damage results from browsing after the seedlings have passed the first season. The damage by browsing may have been unusually small because of the excellent forage in 1919. The occurrence of good germination and an abundance of forage are usually coincident, because both are dependent upon copious rainfall.

Further inspection of Table 30 shows a great increase of damage during the second season. Despite losses, however, areas on which initial establishment was plentiful still show what appears to be adequate survival. This fact may lead to the inference that where dense stands of seedlings spring up, as was the case on extensive areas in 1919, reproduction will succeed in spite of sheep grazing. Instances can be cited which indicate that this has happened in the past, but there are other instances in which dense stands of seedlings have been destroyed by sheep. No doubt intensity of grazing and other conditions must be considered. It is safe to say, however, that under inadequately regulated grazing the chances are decidedly against reproduction, even in a year like 1919. Moreover, an open winter or a dry summer during the first two or three years after germination may so reduce the number of seedlings that those which remain can easily be destroyed by sheep.

Seedlings are better able to withstand browsing after their second year, but the increase in size brings greater exposure to injury. Coarse grass, weeds, and brush are a good protection until the seedlings reach a height of from 4 to 6 inches. After this they are fully exposed, excepting in tops or rock piles, where they may escape for several years longer. The bunch-grass region furnishes an excellent illustration of this statement. Close inspection reveals

considerable numbers of seedlings not only of the 1919 age class, but also of ages ranging from 5 to 10 years. Those below 5 years of age, where protected by grass or brush, are often uninjured; but older specimens are usually damaged, and if they grow high enough to be seen above the grass or brush they are almost invariably reduced to mere stubs. (Pl. XXI and Pl. XXII.) These mutilated survivors tell more eloquently than words what will be the probable outcome of the 1919 seedling crop when unprotected against excessive sheep grazing.

The protective value of coarse grass and brush in the early seedling stage is further demonstrated by counts on bare and covered areas. On a series of almost bare plots (stump patches) the total injured and killed was 87 per cent in August and 73 per cent in November, 1920, as compared with 24 and 27 per cent on plots in the bunch grass and 4 per cent (November) in tops. The total number surviving in the bunch grass in November, 1920, was 7,300 per acre, as against 2,000 per acre on the bare plots, of which 73 per cent are injured. Practically all of the uninjured seedlings in stump patches and similar situations are in the scattering bunches of unpalatable weeds which are undisturbed by sheep.

The consequences of sheep damage are most serious where there are relatively few seedlings to begin with. This is evident on sample plot 5. No reliable counts on these plots are available for 1919, but it is known that the number of seedlings per acre was far below the number on the Wing Mountain and Fort Valley plots. Sample plot 5 is situated near a sheep ranch, and therefore is probably subject to more than average damage. Seedlings in 1921, after three years of such grazing, are only from 16 to 25 per cent as numerous outside as inside the inclosures. The effects in this instance are particularly serious, because even where none have been killed by sheep the number is barely sufficient for satisfactory stocking, allowing for normal mortality.

DAMAGE BY CATTLE AND HORSES.

A comparison of areas grazed only by cattle or horses, or by both, with areas grazed also by sheep (Table 30), confirms the conclusions of Hill and others that damage by cattle and horses is relatively light. Small seedlings are occasionally eaten with other plants, especially bunch grass. Instances have been observed in which serious damage has been done by cattle when the bunch grasses were eaten too close to the ground. Perhaps the greatest amount of damage by cattle and horses to small seedlings results from trampling when the ground is soft. Older plants are eaten under certain conditions, as when the animals are confined without

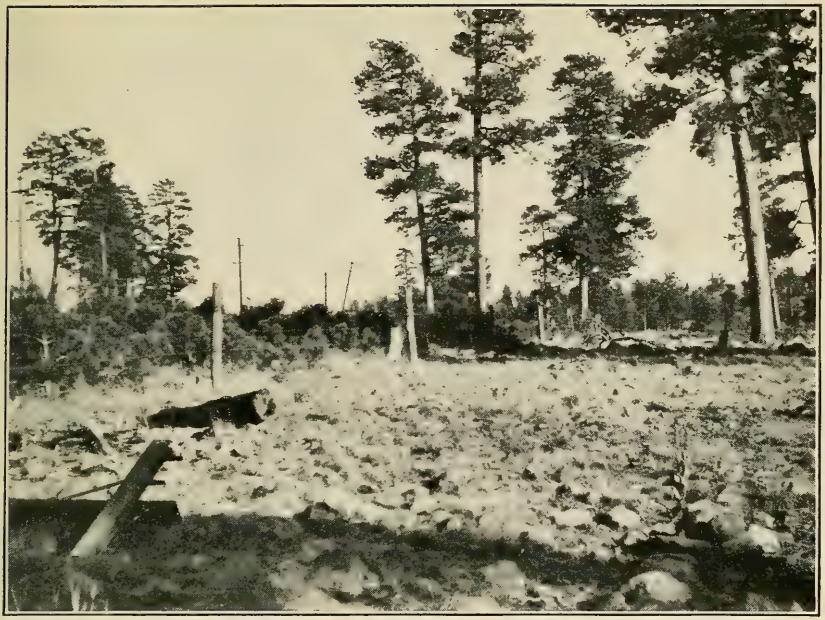
a sufficient amount of palatable feed. Even under these circumstances serious damage is uncommon, as indicated by the fact that pastures in which reproduction is making good progress are as a rule overgrazed. Since from 80 to 90 per cent of all grazing damage to young seedlings is attributable to sheep, the term "sheep damage" is used in this report to cover all classes of injury by grazing, unless there is reason to believe that other animals are responsible in more than the usual degree.

SEASONAL DAMAGE.

Relative damage during different seasons was considered only in a casual way in this study. It confirms Hill's conclusion that little damage occurs in the spring of the year before the new seedling shoots make their appearance and while bunch grasses are tender and palatable to sheep. Usually the new growth begins about June 1. In 1920 it was later on account of the backward season. Table 30 shows that on sample plot 5 very little damage had occurred prior to July 1 of that year. This was apparently due to the fact that sheep had grazed very lightly on this area during the month of June, although they had covered it thoroughly in May. In average seasons considerable damage may be expected after June 1. By about September 1 both leaves and stems have become woody and resinous. This probably accounts for the decrease of damage in the fall, as shown by Hill's figures. It should be borne in mind, however, that if other conditions are such as to induce damage, the difference in various seasons may be relatively small.

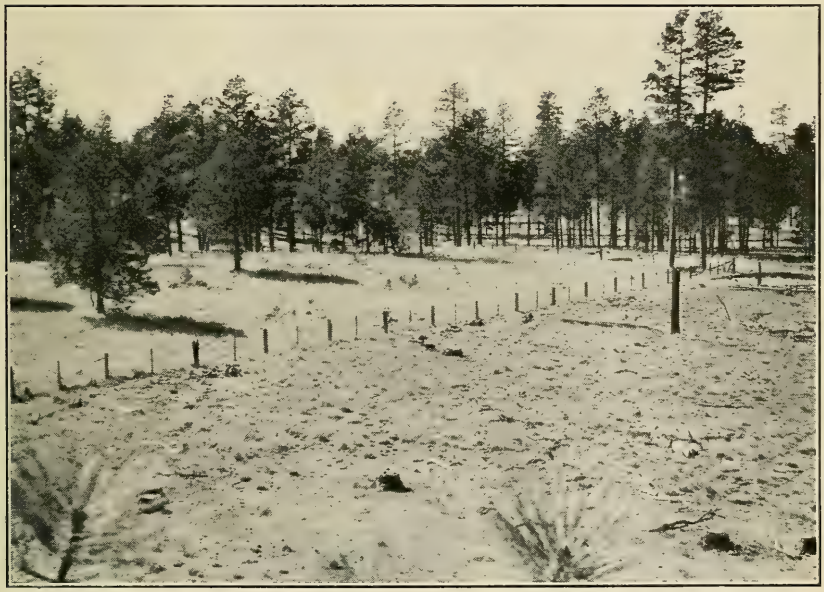
Considerable damage may occur late in the fall or early in the spring, at times when unseasonable snows render herbaceous forage temporarily unavailable. Sheep are usually out of the yellow pine forest during the seasons when heavy snows are liable to occur. In October, 1920, however, many bands were marooned on the Coconino National Forest by a heavy snow. At one camp, where several bands were held for a week during this storm, nearly every seedling between 1 and 3 feet in height was defoliated within a radius of a mile of the camp. Much cattle damage was also in evidence at this time.

Overgrazing.—Hill states that overgrazing is responsible for most of the damage by sheep. Overgrazing may be due to overstocking on the range as a whole, or to localized overstocking, such as results from improperly distributed watering places, continued bedding of sheep on the same grounds, unnecessary trailing, and other well-known abuses. It is pointed out by Hill that a range may be overstocked by sheep because of a deficiency of suitable forage for them, although there may be an abundance of feed for cattle and horses. This type of overgrazing is common on the bunch-grass range.



F—49222A

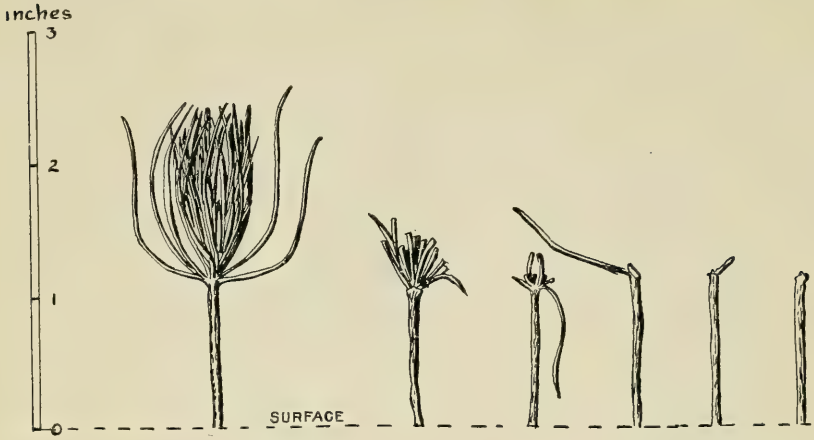
FIG. 1.—SANTA FE RIGHT OF WAY JUST WEST OF RIORDAN, ARIZ. GOOD REPRODUCTION ON FENCED RIGHT OF WAY, NONE ON THE OVERSTOCKED SHEEP AND CATTLE RANGE OUTSIDE.



F—49180A

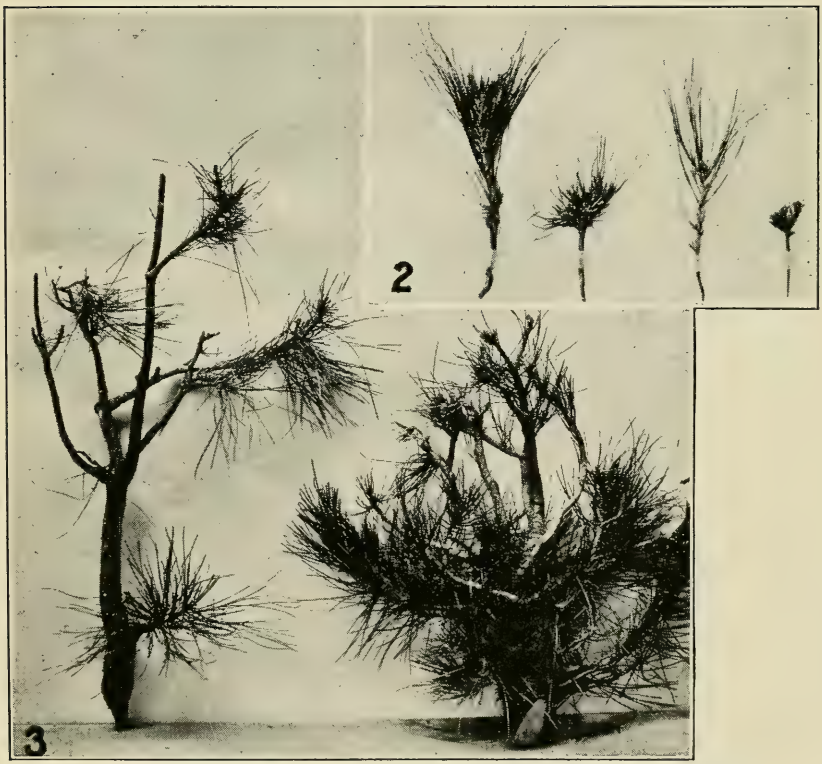
FIG. 2.—SAMPLE PLOT 3A IN THE BUNCHGRASS TYPE, FENCED AGAINST ALL GRAZING SINCE 1910. NOW ABOUT HALF STOCKED WITH SEEDLINGS FROM 5 TO 11 YEARS OLD.

On the surrounding areas, overgrazed by sheep, scarcely a normal seedling above 5 years old is to be found.



F—3-GAP

FIG. 1.—TYPES OF GRAZING INJURY TO SEEDLINGS IN THE COTYLEDON STAGE.



F—4-GAP

FIG. 2.—NORMAL AND INJURED SEEDLINGS 3 YEARS OLD. REPEATED INJURY RESULTS IN RETARDED GROWTH AND ULTIMATE DEATH. FIG. 3.—SAPLINGS APPROXIMATELY 20 YEARS OLD DWARFED AND DISTORTED BY CONTINUOUS INJURY.

F—150548

FIG. 1.—SEEDLINGS IN BRUSH. THE SMALL ONES, 2 YEARS OLD, ARE MOSTLY UNINJURED BECAUSE OF THE PROTECTION AFFORDED BY LIMBS. THE LARGE ONE, ABOUT 5 YEARS OLD, HAS BEEN INJURED BY SHEEP.

Brush ceases to be effective as a protection against grazing after seedlings are above 1 foot in height.

F—5-GAP

FIG. 2.—EXTREME EXAMPLES OF DAMAGE TO ADVANCED REPRODUCTION BY SHEEP.

When the leader extends above a height of about 3½ feet it is practically immune from sheep damage.

The fenced plots 3A and 3B, to which repeated reference has been made in this bulletin, lie in the midst of one of the most extensive bunch-grass regions. Outside the fenced plots the bunch grasses apparently constitute about 95 per cent of the herbaceous vegetation. Sheep scarcely graze these grasses at all, but depend mainly upon the more succulent herbage of the weed type which grows up around stumps and brush piles. Close inspection reveals the fact that considerable amounts of weed forage grow in these situations, but that they are usually so badly overgrazed that the ground appears almost bare. It is estimated that on cut-over lands about 20 per cent of the area is of this character. In the bunch-grass association proper such deterioration has taken place that the species which are palatable to sheep are almost entirely absent. Inside the fence large quantities of vetch and red-and-yellow pea, both excellent sheep forage, grow in mixture with the bunch grasses. Around stumps, corresponding to the bare spots outside, a luxuriant mixture of June grass, barley grass, vetch, red-and-yellow pea, yarrow, geranium, goldenrod, and many other species of the weed type have taken complete possession. A merely casual comparison of conditions inside and outside the inclosures is sufficient to show that from the standpoint of sheep forage the outside range is severely overgrazed.

Tables 13 and 30 show that the areas around stumps, or "stump patches," which bear practically the entire supply of palatable sheep feed on the range at large, suffer much more with respect to damage by sheep than do the surrounding bunch-grass areas. At first thought this relation appears to be contrary to the general opinion that damage by sheep is less on areas stocked with palatable sheep forage than on areas lacking in this type of plants. The fact is, however, that the quantity of good sheep forage is entirely inadequate; hence the patches on which it predominates are very severely overgrazed. If the number of sheep were reduced to such an extent that the areas bearing good sheep forage would not be overgrazed, it is reasonable to expect a decrease of damage to pine reproduction. Such a reduction would also tend to restore the more valuable sheep forage plants in the bunch-grass association and then the range as a whole would be greatly improved from the standpoint of grazing as well as forestry.

BENEFITS FROM GRAZING.

Thus far we have dwelt entirely upon the damage to pine seedlings by grazing. Grazing is in many ways beneficial to reproduction and to the forest as a whole. The value, from the standpoint of fire protection, of keeping down herbaceous vegetation which, if

allowed to accumulate, creates a fire menace, is too well known to require discussion (*9*). It is also generally recognized that the cropping of herbaceous vegetation favors pine reproduction by preventing the suppression of young seedlings. Recent studies described in the chapters on herbaceous vegetation and brush disposal show that competition for moisture by grass and other herbs may be very detrimental to pine reproduction. Proper grazing by cattle and horses can be employed to excellent advantage in subduing this vegetation. Damage to pine seedlings must, however, be rigidly guarded against. In order to secure the maximum benefits from grazing, it must be under control. The distribution of watering places and salting grounds, brush disposal after cutting, and the number of animals on the range must be such that uniform intensity in grazing can be secured.

The opinion is frequently expressed that grazing assists germination by trampling the seeds into the soil. No direct evidence has been produced in proof of this assertion. It is reasonable to believe that such benefits are realized under certain conditions. On loamy soils the hoofs of cattle, horses, and sheep may press pine seeds into the soil or make impressions which provide suitable lodging places. On clay soils, however, the benefits of covering the seed may be offset by the packed condition which results from trampling. Frost action, which honeycombs the surface layers of soil in late fall and early spring, is probably more effective in covering seeds than is grazing.

THE REMEDY FOR SHEEP DAMAGE.

All investigations on damage to western yellow pine reproduction by grazing in the Southwest agree in the conclusion that sheep are responsible for serious damage. A survey of lands logged under the supervision of the Forest Service on the Coconino and Tusayan National Forests reveals a uniform failure of reproduction, excepting where seedlings started in large numbers in advance of cutting. This failure is due not to improper methods of cutting or to unusually adverse climatic conditions, but primarily to excessive sheep grazing. Data accumulated during the past 10 years show that reproduction can be secured with reasonable certainty under the present method of cutting, provided damage by grazing is eliminated, but that under any silvicultural system in which grazing is inadequately regulated reproduction is a gamble against overwhelming odds. Although the situation is less critical on other National Forests, such as the Santa Fe, Carson, Lincoln, Apache, and Sitgreaves, where natural conditions for reproduction are generally favorable, there is evidence that even on these Forests improper sheep grazing may preclude reproduction.

The surest solution of the problem is to exclude sheep. This does not call for wholesale expulsion of sheep from the National Forests. It merely involves temporary removal of sheep from areas which are in the process of restocking. Areas which are adequately stocked will require no exclusion, or only temporary exclusion, to enable the seedlings already on the ground to reach sufficient height to resist excessive damage. The period required for an adequate stand of seedlings to become established and grow beyond danger from sheep grazing is estimated at 20 years. At the end of the reproduction period the lands thus affected can again be thrown open to regulated sheep grazing. Thus, sheep grazing in the yellow pine forest would be handled on a rotation plan in which exclusion would follow or directly precede cutting, and, after the system has been in practice for about 20 years, the closing of new areas for reproduction will be offset by the reopening of those which have been restocked. After the system is once under way the area open to sheep will remain practically stationary. Since something like 160,000 acres of past and prospective cuttings are involved on the Coconino and Tusayan National Forests, heavy initial reductions in the number of sheep are called for. A substantial beginning has already taken place, and present plans provide for additional cuts to be distributed over a period of several years.

Experience throughout the Southwest points to the desirability of securing reproduction in advance of cutting. The heavy seed yields of virgin stands may normally be expected to hasten reproduction and thus shorten the period during which special protection against grazing is required. Protection should begin immediately after the appearance of a good stand of seedlings. Although under favorable circumstances a single seed crop may result in complete restocking, the many uncertainties involved render it advisable to provide adequate protection for 10 years prior to cutting. Some seedlings would die from suppression on the immediate sites of tree groups; but they could easily be replaced after the latter are removed, because of the favorable conditions afforded by such sites.

A program calling for the exclusion of sheep on an extensive scale will obviously interfere to some extent with the sheep industry. The cut in actual numbers is not the greatest object of concern. The greatest problem arises from the private ownership of ranch property, and of water and other improvements necessary to the utilization of the range. Closing ranges on which these developments have been made at private expense involves difficult problems in the adjustment of property rights. Moreover, there is need for additional water development and fencing in order to facilitate the proper handling of stock and shifting of allotment lines. One

solution of this problem lies in Government ownership of range improvements.

It is possible that a less drastic solution may be found by substituting better range management for exclusion of sheep. This would obviate, to a great extent at least, the complications due to private ownership of range improvements. Investigations show that damage is intensified by failure to observe certain fundamental principles now commonly recognized by both stockmen and forest officers. Hill (*11*) states that, "under proper grazing management, reproduction does not suffer an unwarranted amount of damage." Proper grazing management involves adjusting the number and class of stock grazed to the amount and kind of forage suitable to the class or classes of stock, and thus providing adequate, palatable forage suitable for each class of stock available at all times, proper seasonal use, and proper handling of the stock on the range. Strict application of these principles would undoubtedly bring about great improvement. Until grazing management has been more fully tested with reference to reproduction, however, there is grave danger in assuming that it will solve the problem of sheep damage. Its effectiveness and practicability must be demonstrated before it can be accepted as a substitute for sheep exclusion. In order to meet the test, range management must show that it will secure satisfactory reproduction, *originating after management is instituted*, within a period not exceeding by more than 25 per cent the period required where sheep are excluded. The principal types of range and forest conditions should be covered. It must be shown that success is not dependent primarily upon extraordinary conditions of climate and seed production, which can not usually be expected within an ordinary reproduction period of 20 to 25 years. It is doubtful whether grazing management can meet the above requirements on cut-over lands devoid of advance reproduction, because under average conditions such lands will restock very slowly even when undisturbed by grazing, and the injury of as few as 10 per cent of the seedlings annually may preclude success. This is the type of land which is now demanding attention on the Coconino and Tusayan National Forests. By instituting proper grazing management at least 10 years before cutting, thus taking advantage of the heavy seed crops in virgin stands, the chances of success are greatly enhanced. As at least 10 years will be required to secure results, carefully controlled experiments to determine the practical possibilities of range management should be instituted without delay. In the meantime, silvicultural practice must proceed on the assumption that exclusion of sheep during the reproduction period is necessary.

MISCELLANEOUS ENEMIES.

In addition to damage by grazing, which is preventable, western yellow pine reproduction suffers from a number of natural enemies which are only in part or not at all subject to human control. Most conspicuous among these enemies are fire, diseases, insects, and rodents.

FIRE.

The destructive effects of fire are so obvious as scarcely to call for discussion. Western yellow pine seedlings lack the fire-resisting qualities which characterize the longleaf pine of the South. Seedlings below 2 feet high will scarcely resist an ordinary grass fire, and where large amounts of inflammable material are present saplings and even full-grown trees are subject to destruction or serious injury. Although the Forest Service is developing an efficient system of fire protection, occasional conflagrations covering 100 acres or even more may be expected for many years to come. Since fires are most destructive and difficult to control where slash has been left after logging, the desirability of burning the slash is obvious. Moreover, it has been shown under "Brush disposal" that under most conditions the burning of brush favors the establishment of seedlings by eliminating excessive amounts of herbaceous vegetation. Grazing also decreases the destructiveness of fire by preventing excessive accumulations of grass and by breaking up and mixing pine needles and other litter with the soil (*9*). The control of fires is a problem which lies beyond the scope of this investigation.

DISEASES.

Western yellow pine seedlings in this region suffer relatively little from fungous diseases. The damping-off disease attacks first-year seedlings in shaded situations, but where they receive sufficient sunlight comparatively little loss occurs in the forest. A disease answering the description of "stem girdle," by Hartley (*8*) has been observed. A more common disease is apparently what Hartley describes as "sun scorch." It occurs during dry periods of the growing season. This, however, is not a fungous disease, but is due to excessive water loss and is therefore merely a manifestation of drought.

Long has called attention to a twig disease caused by a fungus, probably *Cenangium abietis*, which in certain localities, notably the Prescott National Forest, has injured western yellow pine saplings to a considerable extent.

INSECTS.[20]

Several insects are responsible for serious injury to western yellow pine reproduction. Of these, a white grub, or May beetle larva (*Listrochelus falsus* Lec.), and two tip moths (*Evetria bushnelli* Busck and *E. neomexicana* Dyar) are most destructive. Since no special studies of these insects have been made with reference to their control in the forest, there is little to add to the account of their activities given in previous publications (*18*). It is sufficient to state that the white grub devours the roots of seedlings up to 10 years of age, while the tip moth kills the terminal shoots of seedlings and saplings. Plantations have shown as high as 90 per cent of the plants killed by the white grub in a period of three years. In a broadcast sowing experiment, large patches were cleared of seedlings in their third and fourth years by this grub, and at the present writing fresh work is in evidence, the seedlings now being 7 years old. Almost invariably where examinations have been made in the yellow pine type in the vicinity of Flagstaff, the soil is infested with white grubs. Since this is a common pest in agricultural regions the world over, its range in the yellow pine forests of the Southwest is probably not limited to any particular section. The tip moth, on the other hand, confines its activities mainly to the lower altitudes, doing its worst damage near the lower limits of the yellow pine type. Plants attacked by the white grub are usually killed, but a large proportion of those attacked by the tip moth recover. No practical remedy for either the white grub or the tip moth has been found.

RODENTS.

Seed-eating rodents, such as mice and chipmunks, are an important factor in yellow pine reproduction. In seasons of light seed production they apparently consume the great bulk of the crop. The activities of these pests are undoubtedly the greatest factor in accounting for the failure of broadcast sowing. Birds are also known to pick up seeds, but since hard-shelled seeds usually pass through the alimentary canal of birds without injury, the effect may be merely to transport the seed from one place to another. Birds are known to aid materially in the dissemination and germination of junipers, and it is likely that they play a similar rôle in relation to the pine. The only observed instance of positive damage by birds is in the case of the junco (*Junco dorsalis*), which plucks the seed coats and cotyledons from young seedlings and even cuts down the entire plant. The beneficial effects of birds as a class in

[20] Specific determinations made by the Bureau of Entomology, United States Department of Agriculture.

destroying insects undoubtedly far more than offsets any damage which may be charged against them.

Squirrels, rabbits, rats, gophers, and porcupines are responsible for much damage by gnawing the bark. Squirrels confine their activities mainly to cutting terminal twigs from the older trees. Often the ground underneath a tree is completely covered with leaf tufts cut off by squirrels. The obvious effect is to lower the capacity of the crown as a food laboratory. Rabbits work on seedlings and saplings, from which they gnaw the bark, or, in the case of seedlings, sometimes cut off the entire plant. It is probable that squirrels, rats, and gophers share in the blame for these depredations. Porcupines kill or seriously injure great numbers of seedlings from 1 to 6 feet high by partial or complete girdling. The writer has in mind one area of 125 acres bearing an average stand of 80 seedlings per acre between 1 and 3 feet in height on which scarcely half the plants have escaped injury. In another instance a 5-year-old yellow pine plantation covering one-fifth acre was almost completely exterminated by girdling. It is not positively known, however, whether this was done by porcupines or gophers. Strange to say, adjacent plots of Douglas fir were untouched. Death does not ensue unless girdling is complete, and even in this case seedlings have been known to recover by developing a leader from one of the branches below the girdle. Often the girdled stem becomes so brittle as a result of excessive pitch exudation that it breaks under a load of snow. In winter porcupines work mainly on trees beyond the sapling stage. They bark the stem near the top over a space of several feet. As in the case of younger trees, the wood becomes brittle and the top often breaks off after a heavy snowfall.

SUMMARY.

It has not been possible in this investigation to cover in detail all the conditions occurring in the yellow pine type of the Southwest. It is believed, however, that in solving the reproduction problem where conditions are at their worst, namely, on the Coconino and Tusayan National Forests, principles have been established which will render it comparatively easy to meet the special cases which may arise in other localities.[21]

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[21] As this manuscript was being completed, there appeared in the October, 1921, issue of the Journal of Forestry an article entitled, "Yellow Pine Reproduction," by Walter J. Perry. Perry's article is based entirely upon observations on the Carson National Forest in northern New Mexico. Reproduction is generally excellent in that region and the seedlings are considerably older than those which formed the basis for most of the studies on the Coconino and Tusayan. Notwithstanding the differences in location, soil, climate, and age of reproduction, the two investigations, which were independent of each other, reach identical conclusions on practically all points covered by both.

In the foregoing discussion, eight more or less interrelated factors or complexes have been recognized. They are seed supply, climate, soil, herbaceous vegetation, cutting, brush disposal, grazing, and miscellaneous enemies.

SEED SUPPLY.

An abundant supply of seed is needed to offset consumption by rodents and an extremely high mortality among young seedlings. The minimum seed requirement for average conditions on the Coconino and Tusayan National Forests has been placed at 8 pounds per acre in a good seed year. In other localities this figure might possibly be lowered. On most of the Coconino and Tusayan, about three such seed crops, occurring at intervals of from 3 to 5 years, will normally be required to complete restocking. Under more favorable conditions, such as occur on the Sitgreaves, Apache, Santa Fe, Carson, Lincoln, and, in fact, practically all of the other National Forests in Arizona and New Mexico, two or even one seed crop of the above proportion will usually suffice. All observations agree that the best seed trees are large, sound, healthy individuals which have grown in an isolated position, thus acquiring well-developed crowns and wind firmness. Sufficient emphasis has not heretofore been placed on size. It has been customary to regard all healthy trees down to a diameter of about 11 inches as seed producers. Recent investigations have shown that, as a class, the trees below a diameter of approximately 21 inches contribute relatively little toward the needed seed supply. This is due partly to immaturity and partly to the fact that the great majority of the smaller trees occur in groups, where they are poorly exposed to light and where a large part of their product is ineffective because of poor dissemination. For the above reasons it seems advisable in fixing a minimum limit as to the required number of seed trees to disregard those below 21 inches in diameter breast high. The average minimum for the Coconino and Tusayan National Forests has been placed at 4 trees above 20 inches diameter breast high per acre. Possibly this number can be reduced to three per acre where soil and climatic conditions are more favorable.

CLIMATE.

Climate is perhaps the largest natural complex of factors affecting reproduction in the Southwest, and the greatest single element in this complex is moisture. It is safe to say that an addition of 2 inches to the normal rainfall during the month of June would practically eliminate the reproduction problem in this region. The rainfall of July and August is usually adequate for abundant germination; but often

the seed supply is deficient. Occasionally a good seed crop is wasted because of deficient or irregular summer rains. Drought in September and October sometimes causes heavy losses; frost-heaving usually takes a large toll; but in average years more seedlings die during the drought of June and early July than during all the remaining portion of the year.

SOIL.

Next to climate soil is the most important natural factor. With possibly a few exceptions, none of the soils within the climatic zone of yellow pine in this region contain chemical elements inimical to the reproduction of the species. Reproduction seems to be affected most by the physical condition of the soil, as determined by the proportion of sand or gravel which it contains. Where the soil is sandy or gravelly reproduction is seldom a matter of serious concern. Clay soils, on the other hand, are unfavorable to reproduction. Clay is rendered more favorable by the admixture of large proportions of gravel or stones.

HERBACEOUS VEGETATION.

Herbaceous vegetation favors germination and protects young seedlings against excessive insolation, winterkilling, and frost-heaving; but after the first year these benefits are counterbalanced by the unfavorable effects of root competition and shade. This condition manifests itself in slow growth as well as in a high rate of mortality. Reproduction will usually succeed despite competition from the roots of herbaceous plants, provided that the latter do not attain abnormal density or luxuriance. Such a condition is likely to obtain on the richest soils unless the grass and weeds are held in check. Complete eradication of herbaceous vegetation is not considered necessary, and is distinctly undesirable if accompanied by packing of the soil as in overgrazing, or removal of the loamy surface layer as in deep plowing. Although special methods of shallow cultivation might be expected to yield superior results, they are not considered necessary or economically feasible in the present stage of forest practice. Under present conditions properly regulated grazing appears to be the most practical means of controlling herbaceous vegetation.

CUTTING.

Forest cover assists germination by shading the soil and protects young seedlings against excessive insolation, wind, and frost; but these benefits may later be offset by injurious effects of root competition and shade. Excessive shade is limited to a zone which lies well within the crown projections on the south side of a tree or group, but extends to the north a distance equal to about one-third

the height of the trees, and somewhat shorter distances to the east and west, measuring distances from the outer edge of the crowns. Root competition, in a degree which, though rarely killing seedlings, noticeably retards their growth, occurs on a patch extending from 50 to 75 feet in all directions from the base of tree or outer edge of the group concerned. Beyond these limits the beneficial effects of reduced wind movement equal or exceed the unfavorable influences of shading and soil sapping. It is known, however, that on average sites in this region, western yellow pine seedlings will become established without the shelter of older trees, and that they make the most rapid growth where all competing vegetation, including herbs and shrubs as well as trees, has been eliminated. The primary object of leaving seed trees after cutting should be seed production. Any surplus of trees above the needs for this purpose is likely to prove a handicap to reproduction. A scattered seed-tree method, in which only from four to five choice seed trees per acre are left, promises to give the best reproduction. Such a practice is not generally desirable at the present time, however, because it sacrifices the growing stock made up of young trees now mostly below 20 inches diameter breast high. From a broad silvicultural standpoint, in which continuous production as well as restocking is sought, the best results can be secured by a selection method of cutting which leaves all healthy blackjacks and a sufficient number of yellow pines to provide a minimum of four seed trees above 20 inches diameter breast high per acre. Under favorable conditions of soil and rainfall the number of seed trees might be reduced to three.

The foregoing obviously applies only to areas on which reproduction is absent or greatly deficient at the time of cutting. Where appreciable amounts of advance growth occur, fewer seed trees are required, and this reduction is accomplished by decreasing the number of yellow pines. Provision should always be made, however, for seeding up the open spots left by felled trees. Usually this will be taken care of by the blackjacks which are left. It is distinctly desirable to encourage advance growth as much as possible by providing special protection against fire and grazing during a period of about 10 years prior to cutting. This practice not only gives greater assurance of complete stocking, but may be expected to shorten the reproduction period materially.

BRUSH DISPOSAL.

The effects of a brush cover vary greatly with the character of herbaceous vegetation, the soil, and the density and stage of disintegration of the brush. As a general rule, brush associated with exuberant herbaceous vegetation is detrimental to reproduction, but where the herbs are small and sparse or have been eliminated by

overgrazing or other means, particularly on soils which tend to pack on the surface, properly distributed brush is beneficial. Burning the brush favors reproduction on grassy areas, but not where herbaceous vegetation or litter is absent. Under the latter conditions burning may become detrimental, particularly on compact soils. The above relationships, though apparently complex, are based upon a few simple and well-known principles. Western yellow pine germinates best in a moist but fairly loose loamy or sandy seedbed. Subsequent development of the seedlings is dependent upon an abundance of moisture and sunlight. Decayed organic matter or even thin layers of undecayed grass, needles, and twigs on the soil favor germination; but undecayed litter when over one-half inch in depth interferes with germination and early establishment of seedlings unless rainfall during the first summer is very abundant. The dense mats often created in pulled tops or lopped or scattered brush effectually exclude pine seedlings until this material has rotted down, which requires at least 10 years. Usually, however, there are numerous small spots within a top or patch of lopped or scattered brush in which both surface and overhead cover are just right for germination and growth of seedlings. Theoretically, the seedlings which start in these spots are greatly favored by the conservation of soil moisture and protection against grazing and climatic elements. These conditions are actually realized where there is no herbaceous vegetation, but vigorous types of grass and weeds where abundant develop so luxuriantly under the protection against grazing as to suppress the pine seedlings.

A comparison of pulling tops, lopping, and scattering, as they are usually practiced, reveals the same objectionable features in all three methods. Scattering, however, is subject to better control and is therefore generally preferable to either of the other two methods. Piling and burning is recommended for all typical bunch-grass areas, such as prevail on the Coconino, Tusayan, and portions of the Sitgreaves and Apache National Forests, excepting on overgrazed or otherwise denuded clay soils or on steep slopes subject to erosion. Under the last-named conditions and on bare cinders scattering is usually preferable. On sandy or gravelly soils bearing light ground cover, which prevail on the Santa Fe, Carson, Lincoln, and several other National Forests, brush does not create a grass and weed menace, though it does interfere with germination. Piling and burning is preferable on such sites, excepting where there is danger of erosion; but aside from the fire menace, there is no serious objection to scattering if properly executed.

When advance reproduction exists at the time of cutting, piling and burning should be the invariable practice, unless brush is needed to check erosion. Unburned brush among seedlings and

saplings creates a fire menace. It also covers up and kills many of the smaller seedlings.

GRAZING.

Improper sheep grazing is at present the largest controllable obstacle to reproduction of western yellow pine on the National Forests of the Southwest. Under the methods of cutting practiced by the Forest Service, reproduction is reasonably certain if excessive damage by grazing is avoided; but unless this damage is rigidly controlled failure may be expected, regardless of method of cutting or other silvicultural measures. Instances in which good reproduction has taken place under uncontrolled grazing on private lands or on Government lands before they were placed under Forest Service administration may be explained by the occurrence of unusually favorable climatic conditions, which enable seedlings to start in large numbers, or by the fortuitous absence of such grazing conditions as tend to bring about excessive damage.

Under normal conditions cattle and horses do a relatively small amount of damage, but on areas which are overstocked or which for other reasons supply too little feed for the animals present, cattle and horses may injure a high percentage of the seedlings. The same factors determine to a large extent the amount of damage by sheep. But it can not be said with certainty that under normal grazing conditions sheep will not do excessive damage. Sheep browse yellow-pine seedlings to a considerable extent under normal conditions in the Southwest. Whether the damage falls within the limits permissible from the standpoint of silviculture depends upon a number of circumstances. If pine seedlings spring up in great abundance and at frequent intervals, large losses might be sustained without serious consequences, whereas if reproduction occurs sparingly the same amount of damage would be disastrous. Undoubtedly the intensity of grazing, the amount of palatable forage available for each class of stock, and methods of handling are important factors in the sheep problem; but until it is known more definitely how much weight to give these and other factors, sheep grazing must be regarded as a serious deterrent to the reproduction of western yellow pine in this region.

Until it is demonstrated that grazing management can effectively assure reproduction, sheep should be kept off areas which are in process of restocking until most of the seedlings are about 3 feet high. Under average conditions this will require approximately 20 years. Reproduction can be hastened and the period of exclusion shortened correspondingly by removing sheep about 10 years before cutting, thus taking advantage of the prolific seeding of virgin stands.

MISCELLANEOUS ENEMIES.

Regarding the agencies classed in this category, practically nothing new has been brought to light by this investigation. The fire situation, though always fraught with grave possibilities, is sufficiently well under control so that it need not be a cause for alarm. Diseases, insects, and rodents take an annual toll which in the aggregate must be an important factor in natural regeneration of the forest; but aside from guarding against unusual outbreaks, nothing can be done at the present time to check their depredations.

RULES FOR REPRODUCTION OF WESTERN YELLOW PINE.

The most essential deductions in this investigation may be epitomized in the following general rules:

Encourage advance reproduction by instituting rigid protection against fire and grazing damage 10 years before a proposed cutting. Graze by cattle or horses sufficiently to hold grasses in check, but avoid overgrazing. Until it is demonstrated that sheep can be grazed with consistent safety to pine seedlings, they should be excluded from areas which are being restocked.

If adequate advance growth occurs at the time of cutting, leave in addition to blackjacks only such trees as are needed for fire insurance and to seed up stump patches. If reproduction is lacking at the time of cutting, at least 4 good seed trees per acre above 20 inches in diameter should be left, unless natural conditions are known to be favorable, in which case the number may be reduced to 3.

Burn the brush after logging wherever tall grass or other luxuriant ground cover occurs, and in all cases where reproduction is established, unless the brush is distinctly needed to check erosion. Where ground cover is light or of low stature, the brush may be scattered or pulled, though piling and burning is usually preferable. On compact soils, where ground cover has been destroyed, and on other bare soils, scatter the brush lightly.

Keep out fire; kill rodent pests, including porcupines, gophers, rats, pine squirrels, rabbits, chipmunks, and mice; be on the lookout for disease and insect infestations.

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LEGAL PHASES OF COOPERATIVE ASSOCIATIONS.

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FOREWORD.

It is the purpose of this bulletin to discuss some of the legal questions with respect to the organization, conduct, and operation of cooperative associations. These questions will be considered from the standpoint of incorporated associations with capital stock, incorporated associations without capital stock, and unincorporated associations.

[1] In view of the widespread interest in the legal phases of cooperative marketing, stimulated by the passage of the Capper-Volstead Act, this exhaustive study has been made of the legal phases of the subject by an investigator who not only has had several years of actual legal practice, but has had opportunity to make an intensive study of the economic side of cooperative marketing.

INCORPORATED ASSOCIATIONS OR CORPORATIONS.

NATURE AND CHARACTERISTICS.

A point to be made clear at the outset is that an incorporated cooperative association, whether formed with or without capital stock, is a corporation just as much as an incorporated organization formed to manufacture automobiles, farm implements, or steel. It is true that incorporated cooperative associations are a particular type of corporation, just as incorporated commercial concerns or charitable organizations are particular types. As nearly all cooperative associations are incorporated, and as it is highly desirable, as a rule, that they should be, the greater part of this bulletin will be devoted to a consideration of incorporated associations, and whenever the word "association" is used herein, unless otherwise specified, an incorporated association is meant.

Under the circumstaances a discussion of some of the characteristics of corporations will be in order. These characteristics, it will be kept constantly in mind, are the characteristics of incorporated cooperative associations, as well as of other corporations. The term "incorporation" is used with reference to corporations which do not have capital stock as well as to those which have capital stock. It describes the act of creating a corporation. A corporation is an artificial entity created by the law; it is a creature of the law. The definition of a corporation which is probably more widely employed in this country than any other is that given by Chief Justice Marshall in the Dartmouth College case,[1] where he defines a corporation as "an artificial being, invisible, intangible, and existing only in contemplation of the law."

The existence of a corporation is separate and apart from the stockholders or members who are interested in it.[2] Just as Smith and Jones are different persons, so a corporation is a legal entity distinct from its stockholders or members. Individuality, if the term may be employed, is the dominant distinguishing quality of a corporation. The stockholders or members of a corporation, as well as its officers and directors, may change constantly, but the existence of the corporation is not affected thereby. It lives on as unaffected by these changes as a man is unaffected by changes of clothing. As an engine is separate from the engineer who runs it, so a corporation is separate from its stockholders. The stockholders do not have title to the property of a corporation. They can not transfer the legal title thereto, although all of them join in the execution of papers purporting to transfer the property.[3]

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[1] Dartmouth College *v.* Woodward, 4 Wheat. 518.
[2] Aiello *v.* Crampton, 201 Fed. 891.
[3] City of Winfield *v.* Wichita Natural Gas Co., 267 Fed. 47.

It can be done only through the proper officers or agents of the corporation. If one man acquires all the stock of a corporation the title to the property of the corporation is not in him, as he can not sue in his own name for damages to the property, nor can he thus transfer title to it.[4] A stockholder as such is not an agent of the corporation.[5] A stockholder or member of a corporation has no control over any part of the assets of the corporation prior to its liquidation.

The stockholders or members of a corporation are not generally liable for its debts. In all jurisdictions, however, stockholders or members can be compelled to pay the amount which they have agreed to pay for stock of the corporation or for membership in it. The laws of some of the States, notably New York and New Jersey, permit the organization of cooperative associations with liability by the stockholders or members for debts of the corporation. In every case the statutes of the State should be examined to determine the exact liability of stockholders or members in that State. Frequently it is assumed that an organization is not a corporation if its members or stockholders are liable for its debts. However, if the organization is incorporated it is a corporation, regardless of this fact. The Supreme Court of the United States has held that an organization may be a corporation, although its stockholders are liable for its debts.[6] But, as a general rule, the stockholders of a corporation are not liable for its debts. From this fact results one of the great advantages of incorporation. It enables a man to venture a definite sum of money in a business without risk of losing more in case the business fails.

Every corporation suggests cooperative effort on the part of those interested. Several of the large industrial corporations have each more than 100,000 stockholders. The cooperation in such organizations consists largely in the pooling of the money paid by stockholders for stock. If each of the original stockholders of one of these corporations had acted singly and independently in attempting to establish and increase the particular business involved, much less progress would probably have been made than has been accomplished through the corporation.

ANTIQUITY OF CORPORATIONS.

The idea of a corporation, which is said to have been originated by the Romans, although there is not entire agreement among law writers on this point, is an old one. Corporations were known to

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[4] Button *v.* Hoffman, 61 Wis. 20, 20 N. W. 667; City of Winfield *v.* Wichita Natural Gas Co., 267 Fed. 47.

[5] United States *v.* Strang, 254 U. S. 491.

[6] Liverpool Ins. Co. *v.* Mass., 10 Wall. 566.

the Greeks and Romans centuries before the Christian era. Before the Norman conquest (1066) there existed in England organizations having many of the elements of corporations. Churches were among the first of these organizations. It was not until the middle of the seventeenth century that the large trading corporations of England came into existence. Chief among these was the Hudson Bay Co., which continued, it is said, until 1867.

POWER TO CREATE CORPORATIONS.

The power of creating corporations resides in the sovereign. In England they were originally created by the king; later they were created by acts of Parliament with the express or implied assent of the king.[7]

In this country the power to create corporations belongs to each State and the Federal Government. A State legislature may create a corporation or provide for its creation for any proper purpose and may confer upon it such powers as it sees fit, subject only to such restrictions as are found in the State and Federal constitutions.[8] Congress may create corporations whenever they are necessary, or proper agencies for carrying into execution any of the powers conferred by the Constitution upon the Government of the United States.[9] Congress, because it has exclusive jurisdiction over the District of Columbia, has the same power to create corporations within the District that a State has to create corporations within its borders.[10]

Formerly all corporations in this country were created by special acts; that is, a special act was passed by the legislature of the State every time a corporation was created. It was believed that this practice led to favoritism and unjust discrimination,[11] and gradually it has come to pass that practically all of the States have adopted constitutional provisions prohibiting, with certain exceptions in some States, the creation of corporations by special acts.

Every State now has general statutes which authorize and provide for the formation of corporations. The statutes of some of the States are broad and comprehensive and permit the incorporation under them of corporations to engage in practically every form of lawful activity. Sometimes the statutes permit only the incorporation of particular types of corporations, or of corporations to engage in certain lines of business. Even though a business is lawful, if provision is not made in the statute for the formation of

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[7] Blackstone's Commentaries, Book 1–472.

[8] New Orleans Gas Co. *v.* La. Light Co., 115 U. S. 650; Northern Securities Co. *v.* United States, 193 U. S. 197.

[9] McCulloch *v.* Maryland, 4 Wheat. 316.

[10] Georgetown *v.* Alexandria Canal Co., 12 Pet. 91.

[11] Wells Fargo & Co. *v.* Northern Pacific Ry. Co., 23 Fed. 469.

corporations to engage in that business, they can not be formed in that State.

Those desiring to form a corporation must meet the terms and conditions prescribed by the State. The power of the State in this matter is supreme.[12] The legislature can grant just as little or just as much power to corporations within constitutional limits as it desires. The State can determine upon what conditions corporations may be created and do business within its borders. A cooperative association was incorporated under a statute which among other things provided that all business of associations incorporated under it, except certain enumerated types, should be for cash, and that all persons who extended credit to such associations except for specified purposes should forfeit the amount of the credit thus extended. The statute required that notice to this effect be published on the letter and bill heads, advertisements, and other publications of associations incorporated thereunder. Debts for purposes not contemplated by the statute were incurred by the association, and the creditors sought to throw the association into bankruptcy, but failed, as the court held that they had no claims which could be recognized in bankruptcy, owing to the provision in the statute referred to.[13] In a California case, the validity of a statute providing for the forfeiture of the charters of all corporations which failed to pay a certain tax by a specified date was upheld.[14]

At one time the various States did not have statutes which were adapted to the formation of cooperative associations. There have been, however, many statutes passed by the legislatures of the different States during the last few years for the purpose of providing for the formation of cooperative associations, and at the present time the great majority of the States have statutes especially designed to authorize the creation of such bodies.[15] Although corporations are now, as a rule, formed under general statutes, the act involved in bringing them in existence is regarded as a legislative one, and the rules relative to statutes should be applied in construing charters.[16]

INCORPORATED ASSOCIATIONS—HOW FORMED.

In organizing an incorporated cooperative association, or any other corporation, it is necessary to ascertain and to follow the re-

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[12] City Properties Co. *v.* Jordan, 163 Calif. 587, 126 Pac. 351.

[13] In re Wyoming Valley Water Coop. Ass'n., 198 Fed .436.

[14] Kaiser Land & Fruit Co. *v.* Curry, 155 Calif. 638, 103 Pac. 341.

[15] Copies of the statutes of a particular State on this subject can usually be obtained by writing to the Secretary of State of that State.

[16] Casper *v.* Kalt Zimmers Mfg. Co., 159 Wis. 517, 149 N. W. 754; Lord *v.* Equitable Life A. S., 194 N Y. 212, 87 N. E. 443, 22 L. R. A. (N S.) 420.

quirements of the statute under which it is proposed to incorporate. Such statutes generally require that a certain number of individuals, usually three or more, must unite in articles of association. The term, articles of association, describes the paper or instrument in which those desirous of forming a corporation set forth the various facts required by the law under which they propose to incorporate. Those whose names appear in the articles of association, or, as they are sometimes called, articles of incorporation, are known as the incorporators. The statutes require that the objects and purposes for which the corporation or association is formed shall be clearly stated in the articles of association or incorporation. They usually require that the name by which the cooperative association or corporation is to be known shall be given and that the amount of capital stock, if the association is to have capital stock, shall be stated. Some of the other usual statutory requirements are the length of time the association is to exist and the place where its principal business is to be transacted.

Application to be incorporated or for a charter is usually made to an officer of the State, generally the secretary of state. The articles of association or incorporation which constitute such application are submitted to this officer and, if he finds that the statute under which the incorporators are seeking to incorporate has been complied with and that the purpose of the association is one provided for in the statute, he issues a certificate of incorporation.

The amount of discretion which the secretary of state or like officer has with respect to the acceptance or rejection of an application for a charter is not the same in all the States.[17] Upon the issuance of the certificate of incorporation, the corporation in most States comes into existence. The procedure in the different States is not uniform, but the above gives a general idea of the steps involved. In Georgia and some other States, application for a charter must be made to a court. In some States the charter or the articles of association, or both, must be recorded in the county where the association is to have its principal place of business. In certain States it is necessary to advertise for a given length of time that an application for a charter is being made. The exact moment when a corporation comes into existence varies in the different States and depends upon their statutes. It is believed that all States require the payment of certain fees as an incident to incorporation.

It is highly important that due consideration should be given by those interested in forming a cooperative association, prior to its incorporation, to the matter of determining the particular statute under which to incorporate. The Capper-Volstead Act, which is

[17] Lloyd *v.* Ramsay, (Iowa) 183 N. W. 333.

discussed elsewhere, should be considered. Those interested in forming associations of producers to act as live stock commission agencies should have certain portions of the packer and stockyards act, 1921,[18] in mind, and particularly section 306 thereof, which deals in part with patronage dividends.

Other important matters to be considered at the time of forming an association are the particular provisions to be included in the articles of association, the matter of finances, and of income taxes. To avoid the necessity of amending the charter at a later date, steps should be taken at the time of forming the corporation to see to it that the powers acquired by the association on incorporation are sufficiently broad to permit it to engage in any activity which it may be found advisable to conduct. In the case of associations formed with capital stock those interested should investigate the "blue sky" laws of the State or States in which stock will be sold and govern their actions accordingly.[19] The foregoing as well as other matter appearing herein makes it plain that those desirious of forming an association should have competent advice with respect to the legal aspects of incorporation as well as the conduct of the association's business.

NAME OF ASSOCIATION.

It is absolutely essential that a corporation have a name under which it shall transact its business. Fundamentally the incorporators of a corporation may select any name they choose for the corporation. Statutory provisions now exist in many States in reference to this subject. These provisions frequently require that the name shall clearly indicate that the corporation is incorporated. Sometimes the statutes require that the name shall include the word "corporation," "incorporated," or the abbreviation, "Inc." Restrictions prohibiting the adoption of a name already used or so similar thereto as to be easily mistaken therefor exist in many jurisdictions. The statutes of a number of States prohibit the use of the word "cooperative" in the name of a corporation unless the corporation is a cooperative one or unless it is organized under certain statutory provisions and does business in accordance with them. The term "association" standing alone at common law, and in the absence of a statute, does not have a definite legal meaning. It is true it suggests an organization, but whether the organization is incorporated or unincorporated is unknown. Probably to many it suggests a corporation, and many of the statutes providing for the incorporation of a cooperative association state that the term

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[18] 42 Stat. 159.

[19] Cannon *v.* Farmers' Union Grain Agency, (Oregon) 202 Pac. 725; Kirk *v.* Farmers' Union Grain Agency, (Oregon) 202 Pac. 731.

means a corporation. But in the absence of a statute making it so, the term is not synonymous with corporation. The words "exchange," "union," and "company" likewise do not have an exact legal meaning, but to many they undoubtedly mean the same as the word corporation, and in a number of the States statutes for the incorporation of cooperative associations provide that they are synonymous with the word corporation.

CHARTER—WHAT IT IS.

In the days when corporations were formed through applying to the king, the paper or instrument which was issued by him, if he acted favorably on the application, was called the charter. It was evidence that a corporation had been formed, and it also stated its objects, powers, and limitations. Again, when corporations were created by special acts of the legislature, the act setting forth similar facts was called the charter. At this time, when corporations are created under general statutes, the certificate of incorporation or a similar paper which, as has been previously stated, is issued by the official of the State to whom application is made to be incorporated, is generally looked upon as the charter.

The charter, however, is really much more than the certificate of incorporation. It "consists of the provisions of the existing State constitution, the particular statute under which it is formed, and all other laws which are made applicable to corporations formed thereunder; and of the articles of association or incorporation filed thereunder and the charter or certificate of incorporation granted by the court or officer in compliance with its terms, and its powers, rights, duties, and liabilities are determined accordingly."[20] The foregoing definition makes it clear that the rights, powers, and liabilities of a corporation can not be determined simply by reference to the articles of association and that the charter is something more than a paper.

BY-LAWS.

The making of by-laws is a matter which is usually taken up after the creation of a corporation. The power of a corporation to make by-laws exists at common law. Frequently, however, it is given by the charter or statutes. The statutes of some of the States require that cooperative associations shall adopt by-laws within a certain length of time after their formation. In the absence of a statute requiring it, it is not necessary, although highly desirable, for a corporation to adopt by-laws. The power to adopt by-laws resides in the stockholders or members, and they alone

[20] 14 C. J. 117.

have the power to adopt them in the absence of a provision in the general law or in the charter, placing it in the hands of a select body. They can, however, delegate this right to the directors.

The purpose of by-laws is to provide rules for the regulation of the affairs of the corporation. They can make provision consistent with law and with the charter for any matter or thing relative to the conduct or business of the corporation. By-laws should perform the same office for a corporation or association that a blue print performs for a builder. They should constitute a working plan for the corporation. Among the matters usually provided for in the by-laws of a corporation are the following: The time, place, and manner of calling and conducting its meetings and the giving of notice thereof, the number of members constituting a quorum, the qualifications and duties of directors and officers and their compensation, if any, and suitable penalties for violations of the by-laws.

By-laws are to be distinguished from rules adopted for the guidance of the public dealing with the corporation. The members of a corporation and its directors and officers are generally conclusively presumed to have notice of by-laws and of what they contain, and hence are bound by them, although, as a fact, they may be ignorant of them.[21]

The great importance of members, officers, and directors knowing the provisions of the by-laws of their association is thus apparent. On the other hand, strangers having no knowledge of the by-laws are not bound by them. If notice of the by-laws, either express or implied, reaches strangers it is usually held to be binding on them.[22]

A question which will readily occur to anyone is whether the majority of the members of an association may adopt by-laws which will be binding upon the minority who oppose their adoption.[23] The answer is that they may, if such by-laws are reasonable and consistent with the charter and the general law. However, the majority can not adopt and enforce by-laws which violate the law or run counter to the purpose for which the association was formed. In an Arkansas case, a majority of the members of a corporation sought through a by-law to make what, under the circumstances, was held to be an attempted gift of a sum of money to one of their members. Certain stockholders of the corporation opposed the by-law and later resorted to the courts to prevent the turning over of the money. It was held that the action contemplated was a distinct violation of their rights and was, therefore, illegal.[24] A by-

[21] Brent *v.* Washington Bank, 10 Pet. 594; Columbia Bldg., etc. Ass'ns *v.* Junguist, 111 Fed. 645.

[22] Rathbun *v.* Snow, 123 N. Y. 343, 25 N. E. 379, 10 L. R. A. 355.

[23] Iowa State & Savings Bank *v.* C. Nat. Bank, (Neb.) 83 N. W. 982.

[24] G. W. Jones Lumber Co. *v.* Wisarkana Lumber Co., 125 Ark. 65, 187 S. W. 1068.

law must be general in its application and not aim at a particular member.[25] As indicating the possible scope of by-laws, a Nebraska case is interesting. It was held that a corporation not organized for profit and whose capital stock was fully paid up could lawfully require annual dues from its members.[26] An invalid by-law, if not opposed to public policy, is generally enforced as a contract between the members and between the corporation and its members. For instance, if the members of an association adopt what purports to be a by-law, but which is void for the reason that the corporation or association is not empowered by the law of the State in which it is incorporated or by its charter to adopt the particular by-law, it will, as a general rule, be enforced as a contract.[27] The term "constitution" is frequently used in connection with by-laws. So far as an incorporated association is concerned, it is not believed that the expression has any place. A "constitution" has been held to be only a by-law with an inappropriate name and in no sense a charter.[28]

DIRECTORS AND OFFICERS.

After an incorporated cooperative association or other corporation has been created, it is then necessary to elect directors and officers through whom the association may conduct its business. In some States the directors and officers for the first year or for the purpose of initiating the work of the corporation are chosen before incorporation, but this is not usually required or done. The directors are elected by the members of the association for a given length of time which is sometimes specified in the law of the State. The directors, in turn, as a rule, elect the officers, who are usually chosen from among their number. Unless a statute requires, it is not necessary that the directors should be stockholders or members of the association.

The directors and officers of a cooperative association or other corporation are required to act honestly and fairly in conducting the affairs of the corporation. A director or officer must be open and aboveboard in his transactions with the corporation. He must not take advantage of his position to drive an unjust bargain with the corporation or its stockholders. It is his duty to use his best efforts to promote the interests of the stockholders or members of the corporation, and he can not acquire any adverse interests. The injunction that "No man can serve two masters" is recognized by

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[25] Budd *v.* Multnomah St. R. Co., 15 Oreg. 413, 15 Pac. 659.

[26] Omaha Law Library Ass'n. *v.* Cornell, 55 Neb. 396, 75 N. W. 837.

[27] Strong *v.* Minnesota Automobile Trade Ass'n., (Minn.) 186 N. W. 800; New England Trust Co. *v.* Abbott, 162 Mass. 148, 38 N. E. 432, 27 L. R. A. 271.

[28] Supreme Lodge K. P. *v.* Kutscher, 179 Ill. 340; 53 N. E. 620.

the courts, and contracts entered into by directors or officers with the corporation are scrutinized by the courts with this thought in mind. In a Wisconsin case[29] a corporation employed a man as manager and at the same time sold him 100 shares of stock. A director of the corporation entered into a contract with the manager under which the manager agreed, in case he left the employment of the corporation for any cause, to sell his stock to the director. The contract was held void on the ground that the private interests of the director were antagonistic to those he owed the corporation. The court said:

> The defendant as director had a voice in determining whether or not plaintiff was to continue in the management of the corporate business, whether or not plaintiff's management was for the general interest of the corporation and its stockholders. Obviously his duties as director and his private interest, under the contract to repurchase plaintiff's stock upon the conditions stated were antagonistic and his private interests might oblige him to act contrary to his duties toward the other stockholders. Under such circumstances, such contracts are held void on the ground of public policy, unless all of the stockholders assent thereto.

In the absence of a provision in the statute, charter, or by-laws, a majority of the directors constitute a quorum and when regularly assembled may transact any business which the corporation has a right to transact under its charter.[30]

All of the directors constituting a quorum must be qualified to act. If one of the directors whose presence is necessary to constitute a quorum is disqualified because of his personal interest in the matter that is being considered, the action would not be binding on the corporation or stockholders if a timely effort to set it aside were made. For instance, if a director should offer to sell land to the corporation and as one of a quorum of the directors should vote in favor of its purchase, the transaction would not be binding on the corporation or the stockholders if they seasonably moved to set it aside.[31]

The officers and directors of a corporation are bound by the restrictions imposed upon the corporation by its charter and by-laws, and if they transgress such restrictions are liable for all damages resulting to the corporation therefrom. In a Minnesota case[32] the articles of incorporation limited the indebtedness which the corporation might incur to half the amount of the capital stock actually paid in. The manager, who was also a large stockholder, contracted debts in excess of this amount. It was claimed that the

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[29] Timme *v.* Kopmeir, 162 Wis. 571, 156 N. W. 961, L. R. A. 1919, 1114; see also West *v.* Camden, 135 U. S

[30] In re Webster Loose Leaf Filing Co., 240 Fed. 779.

[31] In re Webster Loose Leaf Filing Co., 240 Fed. 779; Wardell *v.* Railroad Company, 103 U. S. 651.

[32] Fergus Falls Woolen Mills Co. *v.* Boyum, 136 Minn. 411, 162 N. W. 516.

corporation suffered a loss by reason of the excess indebtedness, and it brought suit against the manager to recover the amount of the loss which it claimed it had sustained and recovered a judgment for $3,000 against him.

In probably all of the States there are penal statutes prescribing punishments for various acts by officers and agents of the corporation. Typical among such offenses are securing subscriptions to stock by fictitious persons or deceiving State officials by false entries or records as to the assets of the corporation. In some States directors of corporations are personally liable to creditors of the corporation in the event that they create debts beyond the prescribed capital stock.

An officer or director of a corporation at common law may resign at will,[33] and a statute providing that directors shall hold office for one year and until their successors have been elected and qualified does not prevent resignation during the year.[34]

WHO MAY BECOME MEMBERS.

The question of who may become stockholders or members of a corporation is worthy of consideration. Fundamentally a corporation has the right to determine to whom it will sell stock or issue membership certificates. On the other hand, a corporation can not make an individual a member or stockholder of it without his consent. Within constitutional limits a State undoubtedly could, by statute, require corporations incorporated under it to admit to membership all who apply and meet certain conditions, or who belong to a certain class, but as a rule this is not done.

SUBSCRIBER, STOCK, CAPITAL STOCK.

"A subscriber is one who has agreed to take stock from the corporation on the original issue of such stock."[35] The shares of stock into which the capital stock of the corporation is divided may consist of common stock or common and preferred stock. In Cook on Corporations it is said:

> By common stock is meant that stock which entitles the owners of it to an equal pro rata division of profits, if any there be; one stockholder or class of stockholders having no advantage, priority, or preference over any other shareholder or class of stockholders in the division. By preferred stock is meant stock which entitles its owners to dividends out of the net profits before or in preference to the holders of the common stock. Common stock entitles the owner to pro rata dividends, equally with all other holders of the

[33] Ewald *v.* Medical Society, 130 N. Y. S. 1024; (reversed on other grounds, 144 App. Div. 82).

[34] Briggs *v.* Spaulding, 141 U. S. 132, 154.

[35] Cook on Corporations, vol. 1, p. 43.

stock except preferred stockholders, while preferred stock entitles the owner to a priority in dividends.

Usually the dividend rate on preferred stock is fixed, while that on common stock in commercial corporations is not generally fixed.

Under the statutes of many of the States the right to vote at meetings of the stockholders is limited to the common stockholders, and many of the statutes providing for the incorporation of cooperative associations authorize by-laws limiting the right to vote to common stockholders of the corporation.

The capital stock is usually divided into equal portions called shares; and a share of the capital stock of a corporation is the interest or right which the owner has in the management of the corporation, in its surplus profits, and upon dissolution in all its assets remaining after the payment of its debts.[36]

Shares of stock are usually represented by certificates of stock. A certificate of stock is not the stock itself but simply evidence of its ownership, just as a deed is evidence of the ownership of land. A stockholder or shareholder is one who owns one or more shares of stock. One may be a stockholder, although no certificate of stock has been issued to him,[37] just as one may be the owner of other personal property, although he has never received a bill of sale thereto.

STOCK—HOW PAID FOR.

Stock, as a rule, may be paid for with cash, labor, or other property. There are in most States statutory provisions relative to paying for stock otherwise than with cash, and these should be ascertained and carefully followed. Stock may, in the absence of charter or statutory provisions, be issued in payment for property. The property, however, should be reasonably worth the par value of the stock paid for it. It is the general rule that in order for a payment for stock to be good as against the corporation or creditors thereof, it must be paid for in money or what may fairly be considered as money's worth.[38]

VOTING UNIT.

At common law a stockholder or member of a corporation has but one vote on questions coming before meetings of stockholders, irrespective of the number of shares held by him.[39] Statutes or charters in the case of business corporations generally, prescribe that each share of stock shall be entitled to one vote. Unless each share of

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[36] 14 C. J. 384.

[37] In re Culvers estate, 145 Iowa 1, 123 N. W. 743.

[38] In re Manufactures Box & Lumber Co., 251 Fed. 957.

[39] Taylor *v.* Griswold, 14 N. J. Law 222, 27 Amer. Dec. 33; Simon Borg & Co. *v.* New Orleans City Ry. Co., 244 Fed. 617, 619; Matter of Rochester Dist. Tel. Co. (N. Y.), 40 Hun. 172; 7 R. C. L. 339.

stock is given a vote by statute, those interested in forming an association may, if the incorporation statute authorizes, include a suitable provision in the articles of association establishing what the voting unit at meetings of the stockholders shall be. It would also appear to be the right of members of a corporation to adopt a by-law on the subject where the matter is not controlled by statute or by the charter.[40] However, it has been held in the absence of a provision in the statute or charter on the subject, that a by-law changing the common-law rule is void.[41] If there is a statute or charter provision dealing with the matter it controls, and a by-law to be valid must be in harmony therewith. In a case decided by the Supreme Court of the United States it was said:

> Usually a stockholder is a member of the company, and as such has a right to vote, but it does not necessarily follow that the right increases with the increase in stock, or that the right is lessened in case the number of shares owned by the stockholder should be diminished.[42]

In case there is no provision in the statute, charter, or by-laws on the subject, the common-law rule prevails of one vote for each member or stockholder without regard to the number of shares he may own. With respect to nonstock associations or corporations, this rule also prevails unless changed in one of the ways indicated. It is interesting to note that the generally accepted cooperative principle of one man, one vote, is merely an application of the common-law rule on the subject.

RESTRICTING TRANSFER OF STOCK.

May an incorporated cooperative association or any other corporation restrict the transfer of its stock as against third persons? The answer is yes, if appropriate statutory authority exists in the State in which the association is incorporated. If a statute of the State expressly restricts the transfer of stock except under certain conditions, the matter is clear. This was the situation in a Minnesota case[43] where the statute under which the association was incorporated provided that, "No person shall be allowed to become a stockholder in such association except by the consent of the managers of the same." The court said, "We have no doubt of the validity of such a restriction on the transfer of shares." If the statute of the State under which the association is incorporated authorizes the inclusion of a provision in the articles of association or the certificate of incorporation or the by-laws restricting the trans-

[40] Detwiler *v.* Commonwealth ex rel. Dickinson, 131 Pa. 614, 7 L. R. A. 357.
[41] Taylor *v.* Griswold, 14 N. J. Law 239, 27 Amer. Dec. 33.
[42] Bailey *v.* Railroad Co., 89 U. S. 604, 635.
[43] Healey et al. *v.* Steele Center Creamery Ass'n., 115 Minn. 451, 133 N. W. 69.

fer of stock, there would seem to be no doubt concerning the right of an association to adopt such a restriction.

From the cases that have come before the courts it is apparent that the required statutory authority need not expressly authorize restrictions on the transfer of stock, but general language dealing with this subject would seem to be enough. A few illustrations from decided cases will shed light on this matter. In a recent New York case (1919) the certificates of incorporation of each of the three corporations involved, "Provided that no stock shall be transferred until it was first offered for sale to the other stockholders on terms and conditions to be fixed by the by-laws or by agreement between stockholders, but, in case the offer to sell were refused, the stock would be no longer subject to the conditions." The court held this provision and the by-laws and the agreement connected therewith valid and enforceable. Notice of the restrictions on the sale of stock were stamped on each certificate of stock.[44] Section 10 of the General Corporation Law of New York provides that "The certificate of incorporation of any corporation may contain any provisions for the regulation of the business and the conduct of the affairs of the corporation, and any limitation upon its powers, or upon the powers of its directors and stockholders, which does not exempt them from the performance of any obligation or the performance of any duty imposed by law." It was apparently in pursuance of this provision that the restrictions on the right to transfer the stock were included in the certificates of incorporation. In every case undoubtedly there must be some provision in the statute or general law of the State under which an association is formed to authorize the inclusion in the articles of association or the certificates of incorporation of a provision such as that involved in the New York case. A case presenting similar facts in which a like conclusion was reached was passed upon by the Supreme Court of Massachusetts.[45] If there is nothing in the law of the State authorizing the inclusion of a provision in the articles of association or the certificate of incorporation restricting the transfer of stock, the fact that one was included would undoubtedly be held to be valueless.

A statute may authorize associations incorporated under it to adopt by-laws restrictive of the right to transfer stock. This was the situation in a North Dakota case.[46] The statute empowered associations incorporated under it, "To regulate and limit the right of stockholders to transfer their stock" and to make by-laws for

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[44] Bloomingdale *v.* Bloomingdale, 177 N. Y. S. 873.

[45] Longyear *v.* Hardman, 219 Mass. 405, 106 N. E. 1012; see also Kasper *v.* Kalt Zimmers Mfg. Co., 159 Wis. 517, 149 N. W. 754.

[46] Chaffee *v.* Farmers' Co-op. El. Co., (N. D.) 168 N. W. 616.

the management of its affairs and, "To provide therein the terms and limitations of stock ownership." It was held that a by-law which provided that, "No stockholder shall transfer his stock without first giving the corporation 90 days' notice and option to purchase said stock at par plus the accrued and undivided dividends which are payable per share" was valid. The by-law was referred to on the face of the certificates of stock.

A similar conclusion was reached in an Ohio case involving an analogous statutory provision.[47] Where the statute under which an association is incorporated authorizes the inclusion in the articles of association or the certificate of incorporation or in the by-laws of a provision restricting the transfer of its stock, such a provision will be enforced by the courts of the State where suit is brought, although the association was incorporated in another State. These were the facts in the case last mentioned. In that case the corporation was incorporated in Delaware, but the transactions relative to the stock took place in Ohio, where the corporation had its principal place of business, and the suit was brought there. One is charged with notice of the law of the State under which a corporation is incorporated and of its powers. Even though a by-law restricting the right to transfer stock is unauthorized by the statute under which the corporation is formed, they have been enforced as contracts between the corporation and its members,[48] although a contrary conclusion has been reached.[49] It is not believed that an absolute prohibition on the transfer of stock in an unauthorized by-law would be upheld. Shares of stock at common law are regarded as personal property, and as such all the rules of law relative to such property are applicable. The policy of the law is against prohibitions or such as have that effect on the transfer of property, on the theory that the right of sale or disposition is an inseparable incident of its ownership. But the law permits some restrictions on the right of sale or transfer of real or personal property.[50] In a case decided by the Supreme Court of the United States it was said that "In * * * a joint stock corporation * * * each stockholder whether by purchase or original subscription has the right, unless restricted by the charter or articles of association, to sell and transfer his shares and by transferring them introduce others in their stead.[51]

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[47] Nicholson *v.* Franklin Brewing Co., 82 Ohio 94, 91 N. E. 991, 19 Am. Cas. 699.

[48] New England Trust Co. *v.* Abbott, 162 Mass. 148, 38 N. E. 432, 27 L. R. A. 271; Clothing House *v.* Dickinson, (Minn.) 178 N. W. 957.

[49] Steele *v.* Farmers & Merchants Mutual Tel. Assn., 95 Kan. 580, 148 Pac. 661.

[50] Lathrop *v.* Merrill, 207 Mass. 6, 92 N. E. 1019; Gray Restraints on the Alienation of Property, (2d ed.) p. 399.

[51] Morgan *v.* Struthers, 131 U. S. 246, 254.

LIEN ON STOCK.

If a statute under which a corporation is incorporated or the general law of the State gives a corporation a lien on the stock of a stockholder for debts due the corporation by him, strangers, even though without actual notice, and residents of other States buy the stock subject to the lien. The Supreme Court of the United States has said:[52] "Where by general law a lien is given to a corporation upon its stock for the indebtedness of the stockholder, it is valid and enforceable against all the world." If the statute under which an association or corporation is to be incorporated authorizes the inclusion of a provision in the articles of association or the certificate of incorporation giving the corporation a lien on its stock for any indebtedness due it by a stockholder, such a provision, if included, is also valid against all the world.[53] In a New York case the articles of association provided that, "No shareholder of the association shall be permitted to transfer his shares or receive a dividend or interest thereon who shall owe to the association a debt which shall have become due, until such debt be paid, unless by and with the consent of the Board of Directors of the association." On the face of each certificate of stock involved was the statement, "Subject to the conditions and stipulations contained in the articles of association." Although the plaintiff had no actual knowledge of the limitation on the transfer of stock, he was held bound by the provision in the articles of association.[54]

LIMITATION ON INDEBTEDNESS.

The common law places no limit upon the amount which a corporation may borrow. The amount borrowed may be greater than the capital stock.[55] The general rule is that a debt contracted by a corporation in excess of the limit fixed by statute or by the charter is valid and enforceable against the corporation. A national bank purchased furniture and executed three promissory notes in payment thereof at a time when the amount of its indebtedness exceeded that allowed by a Federal statute. In a suit brought on the notes it was held that the notes were enforceable against the bank. In this case it was said, "We hold, therefore, that an indebtedness which a national bank incurs in the exercise of any of its authorized powers is not void from the fact that the amount of the debt surpasses the limit prescribed by the statute or is even incurred in vio-

[52] Hammond *v.* Hastings, 134 U. S. 401.
[53] Union Bank *v.* Laird, 2 Wheat. 390.
[54] Gibbs *v.* Long Island Bank, 83 Hun. 92, 31 N. Y. S. 406.
[55] Cook on Corporations, Sec. 760.

lation of the positive prohibition of the law in that regard."[56] In an Iowa case[57] it was said, "A corporation debt contracted in excess of the maximum limitation in its articles of incorporation is not void because of such excess." In the case of a corporation there are no public records by which one about to extend credit to it can ascertain the amount of indebtedness already incurred at the time credit is extended, and this furnishes a sufficient reason for holding a corporation liable in cases like those just discussed.

As pointed out elsewhere, officers and directors are liable to the corporation for all damages suffered by it where they exceed the limit of indebtedness fixed by the statute, charter, or by-laws. And directors and officers are made personally liable by statute in some States to third persons for debts in excess of the statutory amount.

LIABILITY OF CORPORATION FOR PROMOTION EXPENSES.

What is the liability of a corporation on contracts made or obligations incurred by its promoters or those who are active in forming and organizing it? The answer is that as a general rule it is not liable unless it recognizes and ratifies the contracts or obligations after its formation. This question arises in connection with the work done or contracts made incident to the promotion of a corporation and prior thereto by those who are active in bringing about the existence of the corporation.

In a North Dakota case,[58] in which the claim involved arose out of work done by a stock subscription solicitor in obtaining subscribers to the capital stock of a corporation to be organized, it was said:

> It is elementary that a corporation is not liable upon contracts entered into by its promoters. Before the corporation comes into existence, it can have no representative and no one is capable of acting for it. Those interested in promoting it may nevertheless contemplate the ultimate payment by corporation of the legitimate promotion expenses. But the corporation does not become liable for such expenses in the absence of a subsequent undertaking in some form.

In a Montana case[59] appears the following:

> In the absence of a statute, a corporation will be held liable for services rendered by its promoters before incorporation, only when by express action taken after it becomes a legal entity it recognizes or affirms such claim, a failure to object when the claim is mentioned is not such an assumption or adoption as will bind the corporation.

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[56] Weber *v.* Spokane Nat. Bank, 64 Fed. 208; see also H. Scherer & Co. *v.* Everest, 168 Fed. 822; Grand Valley Water Users' Association v. Zunbrunn, 272 Fed. 943.

[57] Juskin *v.* Plain Dealer Pub. Co., (Iowa) 165 N. W. 339.

[58] Davis *v.* Joerke, (N. Dak.) 181 N. W. 68.

[59] Kirkup *v.* Anaconda Amusement Co., (Mont.) 197 Pac. 1005; see also Cushion Heel Co. *v.* Hartt, 181 Ind. 167, 103 N. E. 1013, 50 L. R. A. (N. S.) 979.

It is true that as a rule a corporation usually pays the necessary legitimate expenses and costs incurred by those who brought about its formation, but the corporation is not liable for such charges unless it elects to pay them.

DIFFERENCES BETWEEN STOCK AND NONSTOCK CORPORATIONS.

A stock corporation is a corporation having capital stock divided into shares. As evidence of these shares, although not the shares themselves, certificates of stock are usually issued.

Capital stock and stock certificates or stock are generally regarded as characteristics of a business corporation. That is, business corporations usually have capital stock and usually issue certificates of stock. This need not necessariily be true. For it should be remembered that corporations are creations of the legislature and that it can, within constitutional limitations, endow them with such powers and limitations as seem advisable. The State, then, can create business corporations without the elements mentioned. True, this is not generally done, but the power to do so undoubtedly exists. The thought to have in mind is that the legislature has complete control, within constitutional limitations, of the creation of corporations. It may make no provision for their creation, or it may grant those created limited or wide powers.

Nonstock corporations do not have capital stock and usually are not commercial organizations. They generally issue certificates of membership to their members evidencing the right of the members in the corporation. Some of the more common of the corporations of this type are incorporated churches, clubs, or social organizations. In the early history of business corporations having capital stock, certificates of stock evidencing the shares into which the capital stook of the corporation had been divided were not issued, but as time went on some corporations issued certificates of stock evidencing the interest of shareholders in the corporation. The convenience and desirability of stock certificates which could be readily transferred from hand to hand were so apparent that it soon came to be looked upon as a right of a member of a business corporation to have certificates of stock issued to him. And at this time purchasers of stock may generally require the corporation to issue certificates of stock.

From an early date stock certificates were assigned and transferred, and this assignability is generally regarded as one of their leading qualities. Stock of a corporation is regarded as property and, like property of any other kind, is vendible. The whole policy of the law is against restraint on the disposition or sale of property. However, the courts have, where the corporation was authorized to do so,

as previously explained, upheld restrictions on the right of members to transfer shares of stock. At common law, however, shares of stock are regarded as personal property capable of sale, transfer, or succession in any of the ways by which personal property may be transferred.[60]

On the other hand, the interest which a member has in a nonstock corporation, which is usually evidenced by a certificate of membership, at common law is not transferable. In a certain case the plaintiff acquired a certificate of membership from one who was formerly a member of a nonstock corporation, but it was held that this did not constitute the plaintiff a member of the corporation.[61] Of course certificates of membership could be made transferable by statute, by charter, or by authorized by-laws, but in the absence of specific provisions on the subject they are not transferable. Fundamentally, therefore, certificates of membership are not transferable, while shares of stock fundamentally are transferable.

Churches were among the first organizations to be incorporated It is obvious that church membership from its peculiar personal quality is essentially nontransferable. This personal element, which is so apparent in the case of church organizations and in social clubs and kindred organizations, may have been responsible for the establishment of the concept, both in the decisions of courts and in the minds of the people, that membership in a nonstock corporation is not assignable. This principle is basic and in the absence of special provision on the subject is applicable. In view of the foregoing, it is apparent that fundamentally a nonstock association can control its membership better than a stock association.

At common law the stock of a member of a corporation could not be forfeited and the member expelled from the corporation, while nonstock corporations possess the inherent right to expel members for cause.[62] From an early date it was recognized as one of the inherent powers of a nonstock corporation to expel members for cause. Without any charter or statutory provisions on the subject a nonstock corporation may for cause expel members. This, as previously stated, is not true with respect to a stock corporation. Where the charter of a nonstock corporation is silent on the power of expulsion and there are no statutory provisions on the subject, the decided weight of authority is that a member may be expelled for only three reasons: (1) Offenses of an infamous nature indictable at common law; (2) offenses against the members' duty to the corporation; (3) offenses compounded of the two.

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[60] Cook on Corporations, sec. 331; Mobile Mut. Ins. Co. *v.* Cullom, 49 Ala. 558; Boston Music Hall *v.* Corp., 129 Mass. 435.

[61] American Live Stock Comm. Co. *v.* Chicago Live Stock Exchange, 143 Ill. 210, 18 L. R. A. 190.

[62] Fletcher Cyclopedia Corporation, sec. 3960.

In the absence of restrictions in the charter or by-laws of a nonstock corporation or of a statutory provision on the subject, a member may withdraw at any time, and no acceptance is required.[63] On the other hand, shareholders or members of a corporation having capital stock can not, strictly speaking, withdraw from the corporation.[64]

This brief sketch on the differences between stock or nonstock corporations explains why a stock corporation is generally thought of as a commercial organization; that is, as an organization in which money, rather than the personnel of the membership, is the dominant factor. By appropriate charter or statutory provisions a stock corporation may exercise control over its membership resembling that exercised by nonstock corporations. Indeed, no reason is apparent why the legislature could not endow stock corporations, at least at the time of their creation, with as complete control over their membership as that possessed by nonstock corporations. In several jurisdictions at this time statutes providing for the incorporation of cooperative associations with capital stock exist which give such associations control over their members or stockholders comparable with that fundamentally possessed by nonstock corporations.

TRANSFER OF STOCK, LOSS OF MEMBERSHIP.

As has been pointed out elsewhere, an incorporated cooperative association or other corporation may, if appropriate statutory authority exists, restrict the transfer of its stock. At common law, however, shares of stock may be transferred or disposed of in any of the ways known to the law. In the absence of restrictions, therefore, shares of stock may be sold, devised, or transferred like property of any other kind. Transfer books are usually kept by corporations in which the names and addresses of purchasers of stock are kept. This is necessary in order that the officers of the corporation may be able to pay the dividends to those entitled thereto, and in order that notices may be sent to the shareholders. Fundamentally, and this is the rule in the absence of stipulations to the contrary, on the transfer of the stock of a corporation held by an individual the purchaser stands in the place of the former owner as to rights and liabilities, and the former owner has no further interest in the corporation and is free from any further liability.[65]

As previously stated, the general rule is that the owner of stock or the holder of a membership certificate that is fully paid for is exempt from liability to the creditors of the corporation. Limited liability is the general rule relative to the stockholders or members

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[63] Ewald *v.* Medical Society, 130 N. Y. S. 1024, (reversed on other grounds, 144 App. Div. 82); Finch *v.* Oake, 73 L. T. R. (N. S.) 716.

[64] Picalora *v.* Gulf Cooperative Co., 123 N. Y. S. 980.

[65] Whitney *v.* Butler, 118 U. S. 655.

of a corporation. In the case of nonstock corporations one who ceases to be a member of the corporation from any cause in the absence of express provisions to the contrary loses his interest in the corporation and in turn is free from any further liability. At common law one who withdraws, resigns, or is expelled from a nonstock corporation or association is not entitled to any compensation or pay for his interest or equity in the assets of the association. In a Florida case[66] certain members withdrew from a fruit marketing association and then instituted a suit against it. One of the objects of the suit was to obtain compensation for "their interest" in the association. Apparently there was no provision, either statutory or otherwise, on the subject. The court held that the members on withdrawing from the association lost all their rights therein, and that all of the assets of the association could be used for the benefit of the remaining members, and that nothing was due the members who had withdrawn.

DISSOLUTION.

It is clear that through unanimous consent on the part of the stockholders or members of a corporation it may be dissolved.[67] The right of a majority of the stockholders or members at common law to force a dissolution of a corporation against the opposition of the minority is not so well established. Some authorities hold that the majority can force a dissolution,[68] while a contrary doctrine has been laid down.[69] Of course, if there are statutory or charter provisions on the subject they would control. A corporation may cease to exist through the expiration of its charter if the duration of the corporation is limited, and its charter may be forfeited by the State for unauthorized or unlawful action or conduct,[70] or the charter may be repealed through the reserved power of the State.[71] On the dissolution of a corporation after the payment of its debts at common law, its assets are distributed pro rata among the various stockholders or members according to the number of shares held by them.[72] In the case of corporations having preferred stock, the preferred stockholders by express provisions are frequently given preference over the common stockholders in the distribution of the assets of a corporation on its dissolution. The rule that the

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[66] Clearwater Citrus Growers Ass'n. *v.* Andrews, (Florida) 87 So. 903; see also Union Benev. Soc. No. 8 *v.* Martin, 113 Ky. 25, 67 S. W. 38; Dade. Coal Co. *v.* Penitentiary Co., 119 Ga. 824; 19 R. C. L. 1267.

[67] Mobile, etc. R. R. *v.* State, 29 Ala. 573, 586.

[68] State *v.* Chilhowee, etc., Mills, 115 Tenn. 266.

[69] Polar Star Lodge *v.* Polar Lodge, 16 La. Ann. 53; see also Stockholders, etc. *v.* Jefferson, etc. Assoc., (Iowa) 136 N. W. 672.

[70] People *v.* Pullman's Palace Car Co., 175 Ill. 125.

[71] Swan, etc. Co. *v.* Frank, 148 U. S. 603, 611.

[72] Krebs. *v.* Carlisle Bank, 14 Fed. cas. 856; Central, etc. *v.* Smith, 43 Colo. 90.

assets belong to the members of a corporation on its dissolution applies to nonstock[73] as well as to stock corporations. If those interested in a corporation continue to do business in its name after the expiration of the charter or after the dissolution of the corporation in any other manner, they incur personal responsibility and liability in the matter.

CONTRACTS.

NATURE AND CHARACTERISTICS.

A contract has been defined as an agreement between competent parties, upon sufficient consideration, to do or not to do a particular lawful thing.[74] In order to be binding and enforceable a contract must possess mutuality; that is, both parties must be bound, or neither will be. For instance, if one party agrees to sell a certain article, the other must agree to buy, or the agreement is void.[75] A contract or agreement by which a member of a cooperative association appoints the association his agent for the sale and marketing of his products, to be valid should also contain a provision in which the association agrees to act as such agent and do the work in question.

A contract should be in writing and signed by both parties. It should clearly and fully set forth the rights, duties, and obligations of each of the parties. Particular care should be taken to make certain that the contract is clear upon every point involved. For when parties to a contract have apparently set forth in writing the understanding between them with reference to the matter involved, it is presumed to represent the entire agreement of the parties thereto, and ordinarily it cannot be successfully disputed by oral evidence. Every legitimate matter is a proper subject for contract. The law of contracts underlies the entire field of business and enters into every commercial transaction.

CROP CONTRACTS.

One may enter into a valid contract with another under which he agrees to deliver the crop to be grown upon certain land or a part thereof.[76] The number of cases involving crop contracts of cooperative associations which have come before appellate courts for construction are few. One of the most recent decisions[77] is that involving a cranberry association of the State of Washington. In this case the supreme court of that State said:

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[73] Hopkins *v.* Crossley, 138 Mich. 561.

[74] Blackstone's Comm. Book II, 442.

[75] American Oil Co. *v.* Kirk, 68 Fed. 791.

[76] Butt *v.* Ellett 19 Wall 544; Briggs *v.* U. S., 143 U. S. 346.

[77] Washington Cranberry Growers Association *v.* Moore, (Wash.) 201 Pac. 773, 204 Pac. 811.

The appellant makes three principal contentions: First, that the contract is void at common law as against public policy; second, that it is contrary to Article 12, Section 22 of the constitution of this State, which is the section covering the matter of monopolies and trusts, and, third, that the contract is void as being in contravention of the Sherman Antitrust Act, passed by the Federal Congress on April 2, 1890.

The contract was upheld as against the various contentions referred to, and an injunction issued restraining the defendant from disposing of his cranberries outside of the association. The contract involved was one of 60 similar contracts.

An Alabama case,[78] a California one,[79] and two New York decisions[80] also support the validity of such contracts. In Iowa[81] and Colorado[82] the decisions indicate that liquidated damage clause provisions in such contracts are invalid in those States on the ground that they operate to restrain trade unlawfully. For a discussion of this proposition the reader is referred to the sections dealing with liquidated damages and antitrust matters.

POLLING: RIGHT TO DETERMINE GRADE.

A provision in a crop contract authorizing a cooperative association to pool the products of the various members with whom it has contracts is undoubtedly valid. It is a proper subject for contract. Of course, the question of whether the pooling was done fairly and in accordance with the contract is a different matter. The association would be liable to a member in case it failed to act in good faith and in accordance with the terms of the contract.

A stipulation in a contract giving a cooperative association or one or more of its officers or agents the right to determine conclusively the grade and quality of produce delivered under it appears to be valid. This doctrine is subject to the qualification that the officers or agents must act honestly and in good faith. In a case decided by the Supreme Court of the United States,[83]

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[78] Ex Parte Baldwin County Producers Corporation, 203 Ala. 345, 83 So. 69.

[79] Anaheim Citrus Fruit Ass'n. *v.* Yeoman, (Calif.) 197 Pac. 959.

[80] Bullville Milk Producers Ass'n *v.* Armstrong, 178 N. Y. S. 612; Castorland Milk and Cheese Ass'n. *v.* Shantz, 179 N. Y. S. 131.

[81] Reeves *v.* Decorah Farmers Cooperative Society, 160 Iowa 194, 140 N. W. 844, 44 L. R. A. (N. S.) 1108; Ludewese *v.* Farmers M. C. Co., 164 Iowa 197, 145 N. W. 475.

[82] Burns *v.* Wray Farmers' Grain Co., 65 Colo. 425, 176 Pac. 487.

[83] Martinsburg & Potomac R. R. Co. *v.* March, 114 U. S. 549.

A contract for the construction of a railroad provided that the company's engineer should in all cses determine questions relating to its execution, kinds of work to be done, and the compensation earned by the contractor at the rates specified; that his estimate should be final and conclusive; and that whenever the contract shall be completely performed on the part of the contractor, and the said engineer shall certify the same in writing under his hand, together with his estimate aforesaid, the said company shall, within thirty days after the receipt of said certificate, pay to the said contractor, in current notes, the sum which according to this contract shall be due.

It was held that in the absence of fraud or such gross mistake as would necessarily imply bad faith or a failure to exercise an honest judgment, the action of the engineer was conclusive and binding upon the parties. In a Massachussets case[84] it was said:

> It is well settled that where one agrees that another may fix the price for certain property or the sum to be paid for material or services, the decision of the party selected can not be impeached by showing that he has committed an error of judgment or failed to avail himself of all the information which he might have obtained, or has valued the property too high or too low.

These cases announce a principle which would clearly include the right of a cooperative association to determine in good faith the grade and quality or other factors incident to products delivered by a member if authorized to do so by a suitable provision in the contract.

LIQUIDATED DAMAGES.

Liquidated damages are damages the amount of which has been determined in advance by agreement between the parties. Long before the days of Blackstone parties inserted provisions in their contracts that one should pay a certain sum, in case he breached the contract, to the other as satisfaction for the loss sustained by the breach. One of the most common expressions which is used in discussiing the term "liquidated damages" is "penalty." And it is frequently said that a penalty can not be recovered, but that liquidated damages may be. A penalty may, in this connection, be defined as an amount fixed by the parties to a contract to be paid by one of them in case of breach, which is greatly, or perhaps grossly, in excess of the damages which may actually be suffered from such a breach. When the amount fixed is held to be a penalty, such amount can not be recovered but only the actual damages suffered.

A case which well illustrates this view is one in which the defendant entered into a bond to pay $10,000 in case he failed to secure releases, within a year, from certain parties having claims against him. One of the claims amounted to only $9.80, and failure to obtain a release of this claim would have made the entire amount of the bond due and payable. The Supreme Court held that the $10,000 referred to was a penalty and not liquidated damages, and a judgment for 1 cent was affirmed.[85] That the parties to a contract have described the amount to be paid in case of a breach as "liquidated damages" or as a "penalty" is not conclusive upon the

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[84] New England Trust Co. *v.* Abbott, 162 Mass. 148, 38 N. E. 432, 27 L. R. A. 271; see also Berger Mfg. Co. *v.* Huggins, 242 Fed. 853.

[85] Bignall *v.* Gould, 119 U. S. 495.

point,[86] although the term used by the parties has been held to have some weight.[87]

In a certain case the defendant hired a yacht for four months for $10,000 and agreed in the event he failed to return it to pay $75,000, which was stated to be the value of the yacht for the purpose of the contract. The yacht was destroyed, and suit was brought for the recovery of the $75,000. The Supreme Court affirmed a judgment for this amount, and in doing so said in part:

> Whether a particular stipulation to pay a sum of money is to be treated as a penalty or as an agreed ascertainment of damages, is to be determined by the contract, fairly construed, it being the duty of the court always, where the damages are uncertain and have been liquidated by an agreement, to enforce the contract.[88]

In 1904 an agreement was entered into for the erection of two laboratory buildings for the Department of Agriculture in Washington. The contract called for the completion of the buildings in 30 months, and for a delay of 101 days beyond the contract period the Government deducted $200 a day, the amount stipulated in the contract as liquidated damages, a total of $20,200. Later suit was brought against the Government for the recovery of this amount. In holding that no recovery could be had, the Supreme Court of the United States said:[89]

> Courts will endeavor, by a construction of the agreement which the parties have made ,to ascertain what their intention was when they inserted such a stipulation for payment, of a designated sum or upon a designated basis, for a breach of a covenant of their contract, precisely as they seek for the intention of the parties in other respects. When that intention is clearly ascertainable from the writing, effect will be given to the provision, as freely as to any other, *where the damages are uncertain in nature or amount or are difficult of ascertainment, or where the amount stipulated for is not so extravagant, or disproportionate to the amount of property loss, as to show that compensation was not the object aimed at or as to imply fraud, mistake, circumvention or oppression.* There is no sound reason why persons competent and free to contract may not agree upon this subject as fully as upon any other, or why their agreement, when fairly and understandingly entered into with a view to just compensation for the anticipated loss, should not be enforced.

The number of cases relative to liquidated damage provisions involving cooperative associations is not large. In a California case[90] the by-laws of the association, which were signed by the members, provided that members should pay 50 cents per box as liquidated damages for every box of fruit which was not marketed through the association. The defendant marketed 568 boxes outside the asso-

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[86] Northwestern Terra Cotta Co. *v.* Caldwell, 234 Fed. 491, 496.
[87] Tayloe *v.* Sandiford, 7 Wheat. 13.
[88] Sun Printing & Publishing Ass'n *v.* Moore, 183 U. S. 642.
[89] Wise *v.* United States, 249 U. S. 361.
[90] Anaheim Citrus Fruit Ass'n *v.* Yeoman, (Calif.) 197 Pac. 959.

ciation, and it brought suit for $284 and recovered. The court, among other things, said that "the existence and life of the association itself depended upon its being furnished fruit to dispose of in the public market," and that the "standing of the association as a marketing concern" would be affected by a reduction in the amount of fruit marketed.

In two New York cases[91] involving milk associations, provisions in by-laws and contracts for liquidated damages of $2 per cow during the period that milk was not delivered in accordance with the contracts involved were upheld. In an Alabama case[92] the by-laws provided that members should pay the association 3 per cent on the gross selling price of all produce disposed of by them, whether sold through the association or outside, and although the judgment of the lower court was reversed by the Supreme Court of that State on another point, it expressed the view that the by-law was valid and binding. Mention was made of the necessity for providing income for the association, and of the expense the association incurred in preparing to handle and in being in readiness to handle the produce of its members. A case[93] decided by the Supreme Court of Washington in 1921, involving the right of an association to obtain an injunction to prevent a member from disposing of produce outside of the association, is to be regarded as a decision indicating that a liquidated damage clause provision is valid.

In the New York and Alabama cases referred to it was claimed that the provisions relative to liquidated damages were invalid on the ground that they restrained trade. It was also claimed in the Washington case just discussed that the contract involved was in restraint of trade. But the court in each instance overruled this contention. However, in two Iowa cases by-laws providing for the payment of a stipulated amount in case a member disposed of his produce or live stock to a competitor in a particular market were held invalid on the ground that they restrained trade or competition. The by-laws involved in the first[94] of the two Iowa cases to be decided provided that any member of the association should forfeit 5 cents for every hundredweight of produce or live stock sold to any competitor of the association. The association bought and sold the produce and live stock of nonmembers as well as that of members. The by-law in question did not provide that the sum to be paid by members in case they sold to competitors was to be regarded as liquidated damages, but it is doubtful if any weight is to be attached

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[91] Bullville Milk Producers' Ass'n. *v.* Armstrong, 178 N. Y. S. 612; Castorland Milk & Cheese Co. *v.* Shantz, 179 N. Y. S. 131.

[92] Ex Parte Baldwin County Producers' Corporation, 203 Ala. 345, 83 So. 69.

[93] Washington Cranberry Growers' Ass'n. *v.* Moore, (Wash.) 201 Pac. 773, 204 Pac. 811.

[94] Reeves *v.* Decorah Farmers' Cooperative Society, 160 Iowa 194, 140 N. W. 844, 44 L. R. A. (N. S.) 1104).

to this fact. The court emphasized the fact that the association was something more than a mere selling agency, as it dealt with members and nonmembers. Some weight was apparently attached to the fact that the association often paid nonmembers more for their hogs than it paid members.

In a later case [95] the Supreme Court of Iowa held a by-law of a cooperative association invalid as in restraint of competition which, among other things, provided that any member should pay 1 cent per bushel as liquidated damages for all grain which he might sell to competitors of the association who might offer more for grain than the association. It appeared that a member sold 13,000 pounds of pork and 4,000 bushels of oats to competitors of the association in a particular market, and the association attempted to deduct $10.50 on this account, in accordance with the by-law, from dividends amounting to $45.25 which were due him. The member then brought suit against the association to recover the entire amount, $45.25, and won. In holding the by-law invalid in this case, the court did so on the authority of the earlier case which has been discussed.

In a Colorado case [96] a by-law provided that stockholders might sell grain to competitors of the association in a particular town, by paying 1 cent per bushel to the association for all grain so sold. A stockholder who had agreed to the by-law sold 3,500 bushels of grain to a competitor of the association, and it brought suit against him to recover $35. The by-law was held invalid on the ground that it was in restraint of competition, and the association lost the suit. In this case the association dealt with members and nonmembers.

In many of the States there are statutory provisions relative to liquidated damages, and such provisions should be carefully heeded.[97] Whether the provision in the by-law or the contract of an association which purports to require a member to pay a certain sum of money to the association in case he disposes of produce or live stock outside the association will be held valid in a particular State will depend upon the constitution, statutes, and general law thereof.

In all States the amount named as liquidated damages should be a reasonable one and not an amount manifestly in excess of the damages that may be suffered. The by-laws in the Iowa and Colorado cases were held invalid on the theory that they were opposed to public policy in that they tended to restrain trade or competition. No statute seems to have been involved in any of the cases relating to cooperative associations in which the question of the legality of liquidated-damage clause provisions was raised.

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[95] Ludewese *v.* Farmers' M. C. Co., 164 Iowa 197, 145 N. W. 475.
[96] Burns *v.* Wray Farmers' Grain Co., 65 Colo. 425, 176 Pac. 487.
[97] Stark *v.* Shemada, (Calif.) 204 Pac. 214.

RUNNING WITH LAND.

Contracts entered into by cooperative associations with their members sometimes contain clauses which provide that the contract shall "run with the land"; that is, that the purchaser of the farm shall be obligated by the contract entered into by a former owner of the farm with the association. Is such a provision binding on the purchaser of the farm? Of course, if the cooperative association and the purchaser of the farm acquiesce in the matter no question would arise. But in case the purchaser of the farm refuses to recognize the provision in the contract referred to, what is the situation?

The only case that has been found relative to a cooperative association in which this question was raised is an Oregon one.[98] In this case the contract involved contained a provision reading as follows:

> It is understood that the conditions herein contained shall run with the land on which said berries are to be raised and shall bind the parties herein, their heirs, administrators, and assigns.

The court said with reference to this provision:

> The clause providing that the covenants in the agreement should "run with the land" was no doubt considered important. Although it is doubtful whether it could be enforced in an action at law. * * * Whether an equitable remedy would arise out of such a covenant need not here be considered.

It is certain that a purchaser of a farm who had no notice of such a provision in the contract of his predecessor with a cooperative association would not be bound either in law or in equity.[99]

INTERFERENCE BY THIRD PERSONS.

It is a general rule of law, where a stranger to a contract wrongfully induces a party to a contract to commit a breach thereof or disables such party from performing the contract, that the injured party to the contract has a cause of action against the wrongdoer for the loss suffered.[1] This principle was applied in an Oregon case[2] in which it appeared that an association composed of growers of loganberries entered into a contract with a buyer of the berries. The association had contracts with its members obligating them to deliver loganberries to it for delivery to the buyer. The members failed to deliver the berries to the association, and the buyer brought suit against the association and its members. The members claimed that they could not be sued, as the contract was with the association and not with them. In answer to this contention the court said:

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[98] Phez *v.* Salem Fruit Union, 201 Pac. 222, 205 Pac. 970.

[99] Sjobbom v. Mark, 103 Minn. 201, 114 N. W. 746, 15 L. R. A. (N. S.) 1135.

[1] Angle *v.* Chicago, St. Paul Ry., 150 U. S. 1; Westinghouse Co. *v.* Diamond S. F. Co. 268 Fed. 121; Beckman *v.* Masters, 195 Mass. 205, 11 L. R. A. (N. S.) 201.

[2] Phez Co. *v.* Salem Fruit Union, 201 Pac. 222, 205 Pac. 970.

If the defendants be regarded as strangers to the contract of sale between the fruit union and plaintiff, as contended by defendants, the complaint is still sufficient as to the defendant growers under the rule that where a stranger wrongfully induces another to commit a breach of contract, or intentionally disables such other from discharging the obligations of his contract, the wrongdoer is liable in damages, or in a proper case may be enjoined from carrying out his wrongful purposes.

PROMISSORY NOTES.

It is a practice more or less followed by nonstock cooperative associations to receive the notes of their members for specified amounts for the purpose of using them as collateral for loans that may be necessary in the conduct of the association's business and for other purposes. The exact character of such notes depends upon the terms and conditions under which they are given and, of course, upon the law of the particular State. The by-laws of an association usually set forth the agreement between the association and the members relative to the notes, and this agreement would probably in all cases determine the character of the notes as between the association and a member and whether the association could successfully sue a member on such a note. However, this would not necessarily be true, as will be shown later, as between a third person who had received the note of a member from the association.

If the notes executed by the members of an association and delivered to it are accommodation notes—that is, notes executed without consideration and for the purpose of enabling the association to borrow money or obtain credit thereon—then it is settled that the association could not successfully sue a member on such a note. The maker of an accommodation note is known as the accommodation maker. He receives nothing for executing the note and signs it to enable the one in whose favor it is drawn to obtain money or credit from some third party. The fact that a note or other negotiable instrument, no matter what its character, was executed without consideration can always be shown as between the original parties. It furnishes the maker with a complete defense as against the original payee.

If a negotiable note, whether accommodation or otherwise, has been sold, delivered, or transferred before due to a third person in good faith and without notice and for a valuable consideration, the note is enforceable against the maker without reference to intervening equities. This rule is settled.[3] However, where an accommodation note is delivered after it is due, although transferred in good faith to a third person and for a valuable consideration, the

[3] National Bank of Commerce *v.* Sancho Packing Co., 186 Fed. 257.

courts are divided as to whether the maker of the note may plead intervening equities as a defense against the holder.

The general rule, without special regard to accommodation notes, is that one who takes a note or other negotiable instrument after it is due takes it subject to all the equities or defenses that existed between the original parties.[4] For instance, if a note is given without consideration, this could be shown by the maker when sued by one who took the note after it was due.[5]

In the eyes of the law the fact that the note was not paid when it was due is notice to the party taking it from the former holder that there is some defect in the paper. However, with respect to accommodation paper, in view of the fact that it is always given without consideration, the courts in a majority of the States have refused to allow the maker to plead a want of consideration, although the note was taken after it was due.[6] But in some jurisdictions the maker of an accommodation note may successfully plead a want of consideration even as against one who received it in good faith and for a valuable consideration from the original payee.[7]

Where a note is payable on demand, the general rule as to ordinary negotiable commercial paper is that one who takes it an unreasonable time after its execution takes it subject to all defenses that existed between the original parties.[8] Of course, if the maker would not have a defense to a suit on the note if brought by the original payee, he would not have a defense to a suit instituted by one who took the note from the original payee either before or after maturity. With respect to accommodation paper payable on demand, in those jurisdictions where a want of consideration may be shown by the maker as against one who took such paper after it was due, the maker may successfully plead this defense as against one who took the demand accommodation note an unreasonable time after its execution. In a North Dakota case[9] it was said: "It is well established that a note payable on demand is due within a reasonable time after its date, and there are practically no authorities which hold that such a reasonable time can be extended beyond a year."

In a doubtful case it would be a question for the jury to determine whether a note had been sold or delivered as collateral for a loan an unreasonable length of time after its execution. In those States where the defense of a want of consideration can not be

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[4] Otis Elev. Co. *v.* Ford, 27 Del. 286, 88 Atl. 465.
[5] Hill *v.* Shield, 81 N. C. 250, 31 Am. R. 499.
[6] Naef *v.* Potter, 226 Ill. 628, 80, N. E. 1084, 11 L. R. A. (N. S.) 1034.
[7] Chester *v.* Dorr, 41 N. Y. 279; Peale *v.* Addicks, 174 Pa. 549.
[8] Otis Elev. Co. *v.* Ford, 27 Del. 286, 88 Atl. 465.
[9] Adan *v.* Grand Forks Merc. Co., 24 N. D. 645, 140 N. W. 725, 47 L. R. A. (N. S.) 246.

successfully made by the maker of accommodation paper as against one who took it after it was due, it follows that he could not make it as against one who took a demand accommodation note an unreasonable time after its execution. A note executed by a member of a cooperative association and delivered to it, and on which the association could not successfully sue the member, and on which money had not been borrowed or credit obtained, is not a part of the assets of the association. In case the association fails or goes into the hands of a receiver, the receiver could not enforce such a note against the member, for he stands in no better position than the association.[10] On the other hand, if the note is one on which the association could successfully sue, it follows that it is part of the assets of the association, and a receiver would be able to maintain a suit thereon.

AGENCY.

COOPERATIVE ASSOCIATIONS AS AGENT.

As a general rule, whatever an individual may do in person he may do through an agent. And the doctrine is well established that one who acts through an agent acts himself. An agent derives all of his authority from his principal, the one for whom he is acting. Cooperative associations frequently act as agents for members in the sale of produce or the purchase of supplies, and it is therefore important to consider the rights and liabilities of such associations and of their members under these circumstances.

A case[11] decided in 1922, by the Supreme Court of Washington, illustrates one of the important problems which may arise. The Peach Fruit Growers' Co. entered into a contract in its name covering the sale and delivery of fruit of its members. Certain of the members of the Fruit Growers' Co. delivered a part of their fruit to plaintiff, but sold and disposed of a quantity thereof to another dealer. Plaintiff brought suit against the members in question to recover an amount equal to the profits which it claimed it would have made if the members had delivered all the fruit in accordance with the contract. The contract as stated was with the Fruit Growers Co., and did not state that it was made for the benefit of the members. Defendants claimed that for this reason they could not be sued on the contract. The court held that plaintiff could maintain a suit against the defaulting members for the reason that the members had delivered some fruit to plaintiff under the contract. In this connection the court said: "If a principal not disclosed by a contract

[10] Rankin *v.* City Natl. Bank, 208 U. S. 541; Skud *v.* Tillinghast, 195 Fed. 1; In Taskers Estate, 182 Pa. 122.

[11] Barnett Bros. *v.* J. F. Lynn et ux., (Wash.) 203 Pac. 389; see also (Oreg.) Phez *v.* Salem Fruit Union, 201 Pac. 222, 205 Pac. 970.

made by and in the name of his agent subsequently claims the benefit of the contract, it thereby becomes his own to the same extent as if his name originally appeared as the contracting party."

In a companion case,[12] decided at the same time and involving the same contract, the facts being that the members sued had not delivered any fruit under the contract, and hence it could not be said, as was said in the other case, that they had claimed the benefit of the contract, it was held that the plaintiff could not maintain a suit against the members involved, and that if any suit was to be maintained it would have to be against the Fruit Growers' Co. It is clear that in either of the cases just discussed the buyer of the fruit could have sued the Fruit Growers' Co. for the loss sustained through failure to deliver all the fruit contracted for. Of course, if in the contract with the buyer it had been stipulated that it should look to the company exclusively, the members could not have been successfully sued in either case.

It should be noted in this connection that a provision in the contract of an association with its members can not be invoked to relieve the members of liability to third persons under circumstances similar to those involved in the cases just discussed, unless such provision was brought to the attention of the persons with whom the association contracted prior thereto.[13] In the Federal courts, and it is believed in most States, the fruit buyer in the last Washington case referred to above would have been allowed to sue the members who had not delivered a part of their fruit. The Supreme Court of the United States has said: "The contract of the agent is the contract of the principal and he may sue or be sued thereon, though not named therein."[14] In other words, the general rule appears to be that where a contract is entered into with an agent, the agent contracting in his own name, the person for whom the agent is acting, the principal, may sue the other party on the contract, and in turn the principal may be sued by such party; and the fact that the existence of the principal is known or unknown to the opposite party at the time the contract is made is immaterial.[15] Of course, as suggested above, a cooperative association could include a provision in its contract with one with whom it was dealing that would control the situation.

In connection with the general matter now under discussion it should be remembered that members of an association are liable to suit, or may sue, not because they are members of the association, but because they are the principals for whom the association acted.

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[12] Barnett Bros. *v.* S. F. Lynn et ux., (Wash.) 203 Pac. 387.
[13] Kruse *v.* Seiffert, etc. Lumber Co., 108 Iowa 352.
[14] Ford *v.* William, 62 U. S. 287.
[15] Chapman *v.* Java Pac. Line, 241 Fed. 850 and numerous cases therein cited.

It will be remembered that an incorporated cooperative association is an artificial entity, separate and apart from its members. No case has been found where members of an association have been held liable for wrongful acts of negligence of an association while engaged in acting as agent for members in the transaction of certain business or in the doing of certain work authorized by them, but no reason is apparent why they could not be so held in a proper case.

The true conception of this matter can be readily understood when one bears in mind that he is liable, as a general rule, for all acts of his agent while the agent is acting within the scope of his employment. The character of the agent, whether an individual, partnership, or incorporated association, is immaterial. It is upon this theory that automobile owners, whether individuals or corporations, are held liable for injuries to others caused by the negligent driving of their machines by their agents or employees. It is no answer that an agent was not authorized to do the particular act which caused injury or loss if it was done while in the course of the business of his principal or employer.

In a case decided by the Supreme Court of Oregon, in 1920,[16] the plaintiff was the holder of 24 shares of capital stock of the defendant corporation. He entered into contract with the defendant to consign milk produced by him to parties designated by the defendant, and the defendant agreed to collect all moneys due him on such consignments and pay the same to him, less the commission for services as agent of 5 cents per 100 pounds of milk. Other members of the league apparently entered into contracts similar to the one signed by plaintiff. Later a regular purchaser of milk refused to accept delivery of a large quantity shipped by other members of the league, which was then disposed of at less than the contract price. Owing to the loss thus sustained by the producers of this rejected milk, the league in an effort to apportion the loss among the members made deductions from the amount of the sale price of plaintiff's milk, all of which had been accepted and for which the league had received pay. He then brought suit to recover the entire sale price of his milk, less the commission charge of 5 cents per 100 pounds. The court held that he could recover, and in doing so said:

> It was competent for the plaintiff as an individual, irrespective of his holding stock in the defendant corporation, to contract with it as effectually and to all intents and purposes as if he had no share of the stock of the defendant. The contract itself is the measure of the rights and liabilities existing between the plaintiff and the defendant as contracting parties. * * * It was not within the scope of its (defendant's) contract, or of its

[16] Steelman *v.* Oregon Dairymen's League, Inc., (Oreg.) 192 Pac. 790.

articles of incorporation or by-laws, as they appear in evidence, to apportion gains and losses among the several stockholders.

This case emphasizes the fact that a cooperative association which is acting as agent for its members does not have authority, unless conferred in some way, to adjust losses between members. As indicated, if the contract with its members had authorized it to apportion losses, then plaintiff undoubtedly could have been required to bear his proportionate part of the loss.

COOPERATIVE ASSOCIATIONS LIABLE FOR ACTS OF AGENTS.

Incorporated cooperative associations, like other corporations, are liable for the acts of their agents while such agents are acting within the scope of their employment. A corporation may be liable for assault and battery, conversion, nuisance, trespass, libel, and slander,[17] malicious prosecution, wrongful arrest, false imprisonment, fraud, and deceit,[18] It may also be guilty of crimes.[19] It is apparent that all of the various acts enumerated would have to be done by the officers, agents, or employees of a corporation, as a corporation can act in no other way. There is nothing in the nature of an incorporated cooperative association to relieve it from liability under circumstances where any other type of corporation would be liable, and undoubtedly they may be held liable in a proper case for any of the matters mentioned above.

MONOPOLIES—RESTRAINT OF TRADE.

MONOPOLIES.

The term "monopoly" originally referred to a grant by the sovereign of the exclusive right to deal in a certain commodity or to engage in a certain occupation. Queen Elizabeth of England granted monopolies to many of her subjects whom she desired to reward. There were monopolies in salt, starch, calfskins, and many other things. The question of the legality of such monopolies arose in 1602, in a case in which the plaintiff had received the exclusive privilege for 21 years to manufacture playing cards. The defendant impinged this right, and plaintiff brought suit for damages. The defendant pleaded the illegality of the monopoly, and the court held the grant of the monopoly void.[20] Parliament, in 1624, enacted a statute abrogating monopolies save in certain instances.

The term "restraint of trade" originally referred to instances where a man had sold his business and agreed with the purchaser that

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[17] Buckeye Cotton Oil Co. *v.* Sloan, 250 Fed. 712.
[18] Fletcher Cyclopedia Corporations, sec. 3336.
[19] Fletcher Cyclopedia Corporations, sec. 5369.
[20] Darcy v. Allen, 11 Co. 84.

he would not engage in the same business either at that place or any other place or within a given area for a given period of time or at any time. All such agreements appear to have been illegal in the early days of the common law on the theory that they reduced the opportunities of the seller to make a living and tended to monopoly.[21] Later such agreements were upheld if deemed reasonable. At this time they are generally upheld if the restrictions on the right of the seller to engage in business are no greater than those reasonably necessary for the protection of the buyer.[22]

Gradually the terms "monopoly" and "restraint of trade" took on a broader meaning. The term "monopoly" has come to mean the concentration of business in the hands of a few [23] or a combination of persons or corporations for the purpose of raising or controlling the prices of merchandise or any of the necessaries of life.[24] The expression "restraint of trade" is now used as the equivalent of restraint of competition and both terms are employed to describe a situation where illegal means are used to eliminate or restrict competition, or to control prices, or to form a monopoly.

This proposition is illustrated by a Kentucky case [25] in which the plaintiffs were the principal buyers of bluegrass seed in that State. They entered into a secret partnership under which each of the buyers was to continue to operate apparently independently. However, the scheme contemplated that they would secure control of the market for bluegrass seed and suppress competition. The scheme involved the fixing of the price to be paid for seed, the distribution among themselves of seed offered for sale, the price at which seed should be sold, and the sharing of profits and losses. The defendant entered into a contract with a secret agent of plaintiff under which he agreed to sell a quantity of bluegrass seed. He refused to carry out his contract, and suit was brought against him. The Supreme Court of Kentucky, in holding the contract invalid as part of an unlawful scheme, said * * *

> Taking for a foundation the principle that illegal and unreasonable restraint of trade is obnoxious to the spirit of the law * * * this principle will be extended * * * to embrace every condition in which an unlawful attempt is made to restrain trade and control the market and suppress competition by whatever means these ends are sought to be accomplished.

This case illustrates another well-settled principle, namely, that where a contract is held to be in restraint of trade and has not been performed the court will refuse to enforce it or allow damages for

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[21] Anson on Contracts, sec. 255.

[22] Lumbermen's Trust Co. *v.* Title Insurance & Inv. Co., 248 Fed. 212.

[23] National Fireproofing Co. *v.* Mason Builders Ass'n., 169 Fed. 259, 26 L. R. A. (N. S.) 148.

[24] Chicago, W. & V. Coal Co. *v.* People, 114 Ill. App. 75.

[25] Brent *v.* Gay, 149 Ky. 615, 149 S. W. 915, 41 L. R. A. (N. S.) 1034.

its breach. The courts are practically unanimous in holding unlawful all agreements and combinations by and between independent and separate dealers for the purpose of controlling or fixing the prices of commodities.[26] A combination to fix the price of an article of prime necessity was a criminal conspiracy at common law.[27] Many of the cases which have come before the courts involving the propositions discussed under this heading are difficult to reconcile, and many of them are undoubtedly in conflict. The whole subject of monoplies and restraint of trade and allied matters is now more or less comprehensively dealt with by statutes.

SHERMAN AND CLAYTON ACTS.

In 1890 Congress passed the Sherman Act, the first section of which reads as follows:

> Every contract, combination in the form of trust or otherwise, or conspiracy in restraint of trade or commerce among the several States, or with foreign nations, is hereby declared to be illegal. Every person who shall make any such contract or engage in any such combination or conspiracy shall be deemed guilty of a misdemeanor and on conviction thereof shall be punished by fine not exceeding $5,000 or by imprisonment not exceeding one year, or by both said punishments, in the discretion of the court.

The Clayton Act, which supplements the Sherman Act, was passed by Congress in 1914. The Sherman Act was construed in the Standard Oil case in 1910, and it was held that it prohibited all contracts and combinations which amount to an unreasonable or undue restraint of trade in interstate commerce.[28] This conclusion was reached on the theory that the term restraint of trade had a settled meaning at the time this statute was passed and that Congress used the expression in the same sense as that in which it was then commonly employed. Under the antitrust acts referred to, the Supreme Court of the United States in determining whether a defendant is engaged in illegally restraining trade will look largely to how it employs its power and strength.

It was upon this theory that the Supreme Court refused to order the dissolution of the United States Steel Corporation,[29] although it controlled approximately 50 per cent of the steel business of the country. In the opinion in this case the court enumerates some of the practices which had been employed by other combinations and which operated to bring them within the condemnation of the statute. The offending combinations referred to include the American

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[26] 16 R. C. L. 38.
[27] 16 R. C. L. 40; State *v.* Erickson, (Wash.) 103 Pac. 796.
[28] Standard Oil Co. *v.* United States, 221 U. S., 1.
[29] United States *v.* U. S. Steel Corp., 251 U. S. 417.

Tobacco Co.[30] and the Standard Oil Co.[31] Some of the practices in question are mentioned in the following quotation from the opinion:

> The corporation, it was said, did not at any time abuse the power or ascendancy it possessed. It resorted to none of the brutalities or tyrannies that the cases illustrate of other combinations. It did not secure freight rebates; it did not increase its profits by reducing the wages of its employees—whatever it did was not at the expense of labor; it did not increase its profits by lowering the quality of its products, nor create an artificial scarcity of them; it did not oppress or coerce its competitors—its competition, though vigorous, was fair; it did not undersell its competitors in some localities by reducing its prices there below those maintained elsewhere, or require its customers to enter into contracts limiting their purchases or restricting them in resale prices; it did not obtain customers by secret rebates or departures from its published prices; there was no evidence that it attempted to crush its competitors or drive them out of the market, nor did it take customers from its competitors by unfair means, and in its competition it seemed to make no difference between large and small competitors.

This decision makes clear that the legality of a large industrial unit depends on its acts and conduct and not on its size. Bigness which has come about through development along normal lines and without unfair practices or wrongful acts does not constitute illegality.

In the American Tobacco Co., in the Standard Oil Co., and in the United States Steel Corporation cases the legality of a large industrial unit or combination was involved. In each of these cases the industrial unit or combination as it existed at the time suit was brought was the result of the amalgamation or uniting of a number of smaller organizations. As already indicated in the discussion under this heading, there are ways in which the antitrust laws may be violated other than through the illegal organization and operation of large combinations. In the case[32] involving the Eastern States Retail Lumber Dealers' Association it appeared that this association was made up of a number of local retail dealers' associations in various States. Blacklists of all wholesale lumber dealers who sold direct to consumers or builders were circulated by the Eastern States among the local associations of lumber dealers, who in turn circulated such lists among the retail dealers. The evident purpose was to discourage the retail dealers from dealing with such wholesale dealers. The Supreme Court held that such conduct was unlawful as "Unduly suppressing competition," and affirmed the judgment of the lower court enjoining the further circulation of such reports or blacklists.

A manufacturer or dealer, under the decisions of the Supreme Court, can not enter into agreements with those to whom he sells

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[30] United States *v.* American Tobacco Co., 221 U. S. 106.
[31] Standard Oil Co. *v.* United States, 221 U. S. 1.
[32] Eastern States Retail Lumber Dealers' Assn. *v.* United States, 234 U. S. 600.

that they shall not resell except at prices named by him.[33] This is based on the theory that such agreements destroy competition. An unincorporated association[34] of hardwood-lumber manufacturers of various States conducted for the purpose, so it was ascertained, of limiting production and increasing prices through the circulation of reports setting forth facts concerning lumber on hand, sale prices, and rate of production, was held by the Supreme Court to constitute a combination and conspiracy in restraint of interstate commerce and was therefore unlawful. The method employed was called the "Open Competition Plan." Under it each member of the association made daily, weekly, and monthly reports giving minute details of their business. Later these reports were sent out in a condensed form to each of the members of the association.

A conspiracy to "run a corner" in the available supply of a staple commodity such as cotton, normally a subject of interstate commerce, and thereby to enhance artificially its price throughout the country is within the terms of section 1 of the Sherman Act, which is quoted earlier in this discussion.[35]

STATE STATUTES EXEMPTING FARM ORGANIZATIONS.

A large number of the States have statutory provisions which provide that the antitrust laws of the State shall not be applicable to associations of farmers or that associations of farmers incorporated under the statute in which this provision appears shall not be subject to such laws. The following paragraph on this subject, from the act of 1921 of North Carolina providing for the incorporation of cooperative associations, is similar to that found in a number of the States:

> No association organized hereunder shall be deemed to be a combination in restraint of trade or an illegal monopoly; or an attempt to lessen competition or fix prices arbitrarily, nor shall the marketing contracts or agreements between the association and its members, or any agreements authorized in this act be considered illegal or in restraint of trade.

In California the antitrust act provides that,

> "No agreement, combination, or association shall be deemed to be unlawful * * * the object and business of which are to conduct its operations at a reasonable profit or to market at a reasonable profit those products which can not otherwise be so marketed."

In Ohio a statute was enacted in 1921 which places jurisdiction over cooperative associations which have met certain requirements of the law under the public utilities commission of that State. It

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[33] Dr. Miles Medical Co. *v.* Park & Sons Co., 220 U. S. 373; United States *v.* A. Schrader's Son, Inc., 252 U. S. 85; Federal Trade Commission *v.* Beech-Nut Packing Co., 42 Sup. Ct. Rep. 150.

[34] American Column & Lumber Co. *v.* United States, 66 L. Ed. 159.

[35] United States *v.* Patten, 226 U. S. 525.

is therein made the duty of the commission, in case it believes that any such association "Restrains trade or lessens competition to such an extent that the price of any agricultural product is enhanced beyond the cost of production plus a reasonable profit," to proceed against such an association for the purpose of causing it to "Cease and desist from so restraining trade and lessening competition in such article." The Ohio statute in many particulars is similar to the Capper-Volstead Act, which will be discussed later.

SECTION 6 OF THE CLAYTON ACT.

This section reads as follows:

> That the labor of a human being is not a commodity or article of commerce. Nothing contained in the antitrust laws shall be construed to forbid the existence and operation of labor, agricultural, or horticultural organizations, instituted for the purposes of mutual help, and not having capital stock or conducted for profit, or to forbid or restrain individual members of such organizations from lawfully carrying out the legitimate objects thereof; nor shall such organizations, or the members thereof, be held or construed to be illegal combinations or conspiracies in restraint of trade, under the antitrust laws.

It seems to be generally agreed that this section would appear to prevent the dissolution of an organization of farmers which meets the conditions it prescribes, namely, that it is a "labor, agricultural, or horticultural organization;" that it is "instituted for the purposes of mutual help," and does not have "capital stock;" and last, is not "conducted for profit." However, the few decisions of the courts relative to this section indicate that it does not enable them, if desired, to adopt methods of conducting their operations denied to other lawful business organizations. In a case[36] decided by the Supreme Court involving the legality of a secondary boycott by a labor organization it was said:

> As to section 6, it seems to us its principal importance in this discussion is for what it does *not* authorize and for the limit it sets to the immunity conferred. The section assumes the normal objects of a labor organization to be legitimate, and declares that nothing in the antitrust laws shall be construed to forbid the existence and operation of such organizations or to forbid their members from *lawfully* carrying out their *legitimate* objects; and that such an organization shall not be held in itself—merely because of its existence and operation—to be an illegal combination or conspiracy in restraint of trade. But there is nothing in the section to exempt such an organization or its members from accountability where it or they depart from its normal and legitimate objects and engage in an actual combination or conspiracy in restraint of trade. And by no fair or permissible construction can it be taken as authorizing any activity otherwise unlawful, or enabling a normally lawful organization to become a cloak for an illegal combination or conspiracy in restraint of trade as defined by the antitrust laws.

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[36] Duplex Co. *v.* Deering, 254 U. S. 443; see also Buyer *v.* Guillan, 271 Fed. 65.

In a certain case[37] the Aroostook Potato Shippers' Association, acting through a committee, blacklisted certain buyers of potatoes. Members of the association under penalty were forbidden to deal with such buyers. Persons outside the association who dealt with persons so blacklisted were also blacklisted and boycotted. The defendants, members of the association, were indicted for a conspiracy in restraint of trade and fined. The court said with reference to the contention that section 6 relieved the defendants:

> I do not think that the coercion of outsiders by a secondary boycott, which was discussed in my opinion on the former indictment, can be held to be a lawful carrying out of the legitimate objects of such an association. That act means, as I understand it, that organizations such as it describes are not to be dissolved and broken up as illegal, nor held to be combinations or conspiracies in restraint of trade; but they are not privileged to adopt methods of carrying on their business which are not permitted to other lawful associations.

Section 6 of the Clayton Act is still in effect and is not repealed by the Capper-Volstead Act.

RIGHT TO SELECT CUSTOMERS.

It is undoubtedly settled that at common law and in the absence of a statute requiring him to do so a trader or dealer can refuse to enter into business relations with any person whomsoever, and his reason or lack of reason for so doing is immaterial. In a certain case it was said: "We had supposed that it was elementary law that a trader could buy from whom he pleased and sell to whom he pleased, and that his selection of seller and buyer was wholly his own concern."[38] This principle applies just as fully to cooperative associations or other corporations as it does to individuals. However, the courts have never held that two or more independent dealers may agree without a legal cause not to do business with another. Again, when an individual, firm, or corporation does not rest content with refusing to have business relations with a certain person, but endeavors to compel third persons to refrain from having business relations with such person, the law is violated. This was the situation in the case involving the Aroostook Potato Shippers' Association referred to above. Had the association and its members simply refused to deal with the buyers in question there is little doubt but that the law would not have been violated, but when efforts were made to compel third persons to refrain from dealing with such buyers the law was violated.

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[37] United States *v.* King, 229 Fed. 275, 250 Fed. 908.

[38] Great Atlantic & Pacific Tea Co. *v.* Cream of Wheat Co., 227 Fed. 46; see also United States *v.* Colgate Co., 250 U. S. 300; Leech *v.* Farmers' Tobacco Co., 171 Ky. 791, 188 S. W. 886.

CALIFORNIA ASSOCIATED RAISIN CO. CASE.

In September, 1920, the Government brought suit against the California Associated Raisin Co., charging it with monopolizing and restraining trade in violation of the antitrust laws. In September of that year a stipulation was entered into in lieu of an injunction requiring the Raisin Co. to release more than one-fourth of its holdings of raisins (40,000 tons) to competitors and to abandon the "firm at opening price" contract and those involving guaranties against decline. It was also required to announce through advertisements in the newspapers of Fresno County, Calif., its willingness to release all grape growers who claimed that they were coerced into signing contracts with it.

This case was disposed of in January, 1922, by the entry of a consent decree which enjoins and restrains the Raisin Co. from eliminating or decreasing competition in interstate or foreign commerce in raisins or raisin grapes by the purchase, lease, or control of the plant of any competitor or by means of any contract or concert of action with an existing or prospective competitor. It is also enjoined from securing or attempting to secure contracts with growers of raisin grapes by means of coercion or duress, or which eliminate or restrict or prevent others from freely competing to secure contracts with the growers of raisin grapes in California. All contracts entered into with raisin growers must contain a provision authorizing the grower to terminate the contract at the end of the first three years thereof or at the end of any two-year period thereafter; making or entering into contracts for the sale of raisins under which the quantity of raisins to be delivered to any purchaser or the price to be paid therefor is to be subsequently determined by the Raisin Co., in accordance with the practice known as "firm at opening price" or under which the Raisin Co. agrees to indemnify any purchaser against loss on account of a future decline in the market price of raisins, are forbidden; purchasing or agreeing to purchase raisins or raisin grapes from a competitor for the purpose of enabling the Raisin Co. to fix the price of such product or to diminish competition; agreeing or combining either among themselves or with others to lessen or eliminate the supply of raisins or decrease the production or supply of raisin grapes or to diminish competition through the destruction or waste of raisins or otherwise; making a contract with a competitor for the packing of raisins exclusively for the Raisin Co. with an agreement of "exclusive dealing"; making a competitor the agent of the Raisin Co., with authority to sell raisins or raisin grapes at fixed prices, or excluding or preventing a competitor from marketing raisins or raisin grapes for himself or another; making contract under which the purchaser is obliged to

resell raisins or raisin grapes at prices fixed in advance of such resale; making it a condition of any agreement or understanding that the purchaser of raisins or raisin grapes shall not deal in the products of a competitor of the Raisin Co., are all enjoined.

Jurisdiction over the case was retained by the court for the purpose of enforcing the provisions of the decree or of modifying it in case any of its provisions should be found inappropriate or inadequate. Two of the most significant elements involved in the decree are that the "firm at opening price" contracts must be abandoned and that the resale prices of raisin grapes or raisins can not be fixed by the company.

CAPPER-VOLSTEAD ACT.

The Capper-Volstead Act became a law on February 18, 1922. It is entitled "An Act to authorize association of producers of agricultural products," and reads as follows:

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled, That persons engaged in the production of agricultural products as farmers, planters, ranchmen, dairymen, nut or fruit growers may act together in associations, corporate or otherwise, with or without capital stock, in collectively processing, preparing for market, handling, and marketing in interstate and foreign commerce, such products of persons so engaged. Such associations may have marketing agencies in common; and such associations and their members may make the necessary contracts and agreements to effect such purposes: *Provided, however*, That such associations are operated for the mutual benefit of the members thereof, as such producers, and conform to one or both of the following requirements:

First. That no member of the association is allowed more than one vote because of the amount of stock or membership capital he may own therein, or,

Second. That the association does not pay dividends on stock or membership capital in excess of 8 per cent per annum.

And in any case to the following:

Third. That the association shall not deal in the products of nonmembers to an amount greater in value than such as are handled by it for members.

Sec. 2. That if the Secretary of Agriculture shall have reason to believe that any such association monopolizes or restrains trade in interstate or foreign commerce to such an extent that the price of any agricultural product is unduly enhanced by reason thereof, he shall serve upon such association a complaint stating his charge in that respect, to which complaint shall be attached or contained therein a notice of hearing, specifying a day and place not less than 30 days after the service thereof, requiring the association to show cause why an order should not be made directing it to cease and desist from monopolization or restraint of trade. An association so complained of may at the time and place so fixed show cause why such order should not be entered. The evidence given on such a hearing shall be taken under such rules and regulations as the Secretary of Agriculture may prescribe, reduced to writing, and made a part of the record therein. If upon such hearing the Secretary of Agriculture shall be of the opinion that such association monopolizes or restrains

trade in interstate or foreign commerce to such an extent that the price of any agricultural product is unduly enhanced thereby, he shall issue and cause to be served upon the association an order reciting the facts found by him, directing such association to cease and desist from monopolization or restraint of trade. On the request of such association, or if such association fails or neglects for 30 days to obey such order, the Secretary of Agriculture shall file in the district court in the judicial district in which such association has its principal place of business a certified copy of the order and of all the records in the proceeding, together with a petition asking that the order be enforced, and shall give notice to the Attorney General and to said association of such filing. Such district court shall thereupon have jurisdiction to enter a decree affirming, modifying, or setting aside said order, or enter such other decree as the court may deem equitable, and may make rules as to pleadings and proceedings to be had in considering such order. The place of trial may, for cause or by consent of parties, be changed as in other causes. The facts found by the Secretary of Agriculture and recited or set forth in said order shall be prima facie evidence of such facts, but either party may adduce additional evidence. The Department of Justice shall have charge of the enforcement of such order. After the order is so filed in such district court and while pending for review therein the court may issue a temporary writ of injunction forbidding such association from violating such order or any part thereof. The court may, upon conclusion of its hearing, enforce its decree by a permanent injunction or other appropriate remedy. Service of such complaint and of all notices may be made upon such association by service upon any officer or agent thereof engaged in carrying on its business, or on any attorney authorized to appear in such proceeding for such association, and such service shall be binding upon such association, the officers, and members thereof.

This act is a statutory declaration by Congress that, so far as interstate or foreign commerce is concerned, farmers, planters, ranchmen, dairymen, nut or fruit growers may act together in associations, corporate or otherwise, in collectively processing, preparing for market, handling, and marketing in such commerce the products of persons so engaged, and that they may make the necessary contracts to effect such purposes. Whatever doubt may have previously existed on this subject is apparently resolved by this statute. However, as stated in the act, "If the Secretary of Agriculture shall have reason to believe that any such association monopolizes or restrains trade in interstate of foreign commerce to such an extent that the price of any agricultural product is unduly enhanced thereby," he may, following a hearing, if he finds that the price of any agricultural product has been unduly enhanced from either of the causes specified, issue an order directing such association to cease and desist from monopolizations or restraint of trade.

This act has no application to purely purchasing associations or cooperative stores, for the reason that it relates only to associations that are composed of farmers, planters, ranchmen, dairymen, nut or fruit growers who are engaged in collectively processing, preparing for marketing, handling, and marketing in interstate and for-

eign commerce the products of persons so engaged, and then only with such associations as have complied with the conditions of the statute.

The question of whether an association is liable for income taxes is one that is not resolved by this act. Whether an association is liable for income taxes is to be determined by the income tax statutes and the regulations issued under them.

This act does not provide for the incorporation of cooperative associations and makes no provision for their formation. Those interested in organizing or incorporating such associations should look to the laws of their respective States relating thereto. The act does not change nor supersede laws of the various States affecting or relating to the regulation of cooperative associations. So far as this act is concerned, such State laws are all in effect. Compliance with the conditions set forth in this act does not relieve an association from the operation of State laws.

Congress under the Constitution has control over interstate and foreign commerce, and this act deals only with the operations of cooperative associations in such commerce, and then only with such associations as comply with certain conditions prescribed therein. The test which those interested in an association should apply to learn if their association comes within the scope of the act is—does the association meet the conditions set forth therein? These conditions are:

A. "That persons engaged in the production of agricultural products as farmers, planters, ranchmen, dairymen, nut or fruit growers may act together in associations, corporate or otherwise, with or without capital stock, in collectively processing, preparing for market, handling, and marketing in interstate and foreign commerce such products of persons so engaged." This and other language which appears in the act makes it plain that a cooperative association to come within the act must have only producers as stockholders or members. This is true, whether it is incorporated or unincorporated and whether it is organized with or without capital stock. It is clear from the foregoing that an association that is in part composed of, or whose membership contains, or a part of whose stock is held by, those who are not producers does not come within the act. This would, of course, exclude all associations that have other than producers as members or stockholders.

B. Associations that desire to come within the act must be operated for the mutual benefit of the members thereof, as such producers, and conform to one or both of the following requirements: First. That no member of the association is allowed more than one vote because of the amount of stock or membership capital he may own therein, or, second, that the association does not pay dividends on stock or membership capital in excess of 8 per cent per annum. And

in any case to the following: Third, that the association shall not deal in products of nonmembers to an amount greater in value than such as are handled by it for members.

Associations must comply with either the first or second condition and may comply with both. As the first condition embodies the one-man one-vote principle, all associations operating on this basis, or which elect to operate on this basis, need not, unless they wish to do so, give consideration to the second condition. Of course, an association, if it desires, may operate in accordance with both of these conditions, but it will come within the scope of the act by complying with only one of them, if it complies with the other conditions of the act.

If an association elects to operate under the second condition, dividends on stock or membership capital are limited to 8 per cent per annum. This does not mean that stock may be owned by or sold to nonproducers so far as this act is concerned. Only associations whose stock is entirely held by or whose membership is entirely made up of producers can come within the act. It is not necessary for associations operating under the act to pay dividends in any amount unless they elect to do so. It is entirely a matter of choice with them. If, however, an association elects to operate under the second condition, dividends, if paid, must not exceed 8 per cent per annum.

All associations desiring to operate under the act must meet the third condition, which is that the value of the products handled for nonmembers shall not exceed the value of those handled for members. This condition does not mean that an association shall handle any business for nonmembers. It may do so or not, as it sees fit. If it does handle such business, however, the act specifically provides that the value of the products handled for nonmembers must not exceed the value of the products handled for members.

Under section 2 of the act it is the duty of the Secretary of Agriculture, if he believes that any association operating under it monopolizes or restrains trade in interstate or foreign commerce to such an extent that the price of any agricultural product is unduly enhanced by reason of such monopoly or restraint of trade, to serve upon such association a complaint with respect to such matters, requiring the association to show cause why an order should not be issued directing it to cease and desist from monopolization or restraint of trade. After a hearing, if the Secretary of Agriculture believes that such an association monopolizes or restrains trade in interstate or foreign commerce to such an extent that the price of any agricultural product is unduly enhanced thereby, the act provides that he shall issue an order reciting the facts found by him and directing such association to cease and desist from monopolization or restraint of trade. If such order is not complied with by the association within 30 days,

the Secretary of Agriculture is then required to file a certified copy of the order issued by him, together with certified copies of all records in the matter, in the District Court of the United States in the judicial district in which such associaiion has its principal place of business. The Department of Justice has charge under the act of the enforcement of such order. The District Court of the United States is given jurisdiction to affirm, modify, or set aside the order or to enter such other decree as it may deem equitable.

FEDERAL TRADE COMMISSION.

UNFAIR COMPETITION.

The act[39] of September 26, 1914, created the Federal Trade Commission. The act states that unfair methods of competition in commerce are unlawful and provides that "the commission is empowered and directed to prevent persons, partnerships, or corporations, except banks and common carriers subject to the acts to regulate commerce, from using unfair methods of competition in commerce."

The term "commerce" as defined in the act means commerce, interstate or foreign, or in any Territory of the United States or the District of Columbia. The term "unfair competition" is not defined in the statute. At common law unfair competition consisted in the palming off by one vendor or manufacturer of his goods as those of another.[40] The term "unfair competition" as used in the act undoubtedly means all that it imports at common law and, in fact, it apparently has a broader significance and scope than it had at common law.

The act provides that the commission after a hearing may issue an order requiring the person, firm, or corporation involved to cease and desist from unfair competition. In the event the order is not obeyed, the commission may apply to the Circuit Court of Appeals of the United States within any circuit where the method of competition in question was used, or where such person, firm, or corporation resides, for the enforcement of its order. Any party against whom an order is issued may appeal to the Circuit Court of Appeals, from which court an appeal lies to the Supreme Court of the United States.

A few illustrations will shed light on the scope of the work of the commission. In 1919 the commission issued an order against Armour & Co. and the Farmers' Cooperative Fertilizer Co. It appeared that the Farmers' Cooperative Fertilizer Co. was a subsidiary of Armour & Co., and that it was not an organization of farm-

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[39] 38 Stat. 717.

[40] Howe Scale Co. *v.* Wyckoff, 198 U. S. 118.

ers, as the name implied. The order required the Farmers' Cooperative Fertilizer Co. to show on its letterheads and on its places of business that it was a sudsidiary of Armour & Co.

Attempts by an association of harness manufacturers and by a saddle-makers' association to compel the separation of the wholesale and retail harness dealers by refusing to recognize those who engaged in both the wholesale and retail trade as authorized jobbers and to prevent the sale by manufacturers of accessories to such persons was held in a certain case to be unlawful and subject to action by the Federal Trade Commission. In this case, as indicated, the two associations attempted through the membership of each to prevent manufacturers, jobbers, and wholesalers from selling direct to consumers.[41]

The Winsted Hosiery Co. has for many years manufactured underwear which it sells to retailers throughout the United States. It brands or labels the cartons in which the underwear is sold as "Natural Merino," "Gray Wool," "Natural Wool," "Natural Worsted," or "Australian Wool." The Federal Trade Commission[42] instituted proceedings against this company, calling upon it to show cause why use of these brands and labels, alleged to be false and deceptive, should not be discontinued. After appropriate proceedings an order was issued which directed the company to—

> Cease and desist from employing or using as labels or brands on underwear or other knit goods not composed wholly of wool, or on the wrappers, boxes, or other containers in which they are delivered to customers, the words "Merino," "Wool," or "Worsted," alone or in combination with any other word or words, unless accompanied by a word or words designating the substance, fiber, or material other than wool of which the garments are composed in part (e. g., "Merino, Wool, and Cotton"; "Wool and Cotton"; "Worsted, Wool, and Cotton"; "Wool, Cotton, and Silk"), or by a word or words otherwise clearly indicating that such underwear or other goods is not made wholly of wool (e. g., part wool).

The Winsted Hosiery Co. petitioned the Circuit Court of Appeals for the Second Circuit to set aside the order of the commission, and this was done. The Federal Trade Commission then carried the case by certiorari to the Supreme Court of the United States. That court found that the order of the commission was a proper one, and in upholding the right of the commission to issue the order it said:

> The labels in question are literally false, and, except those which bear the word "Merino," are palpably so. All are, as the commission found, calculated to deceive, and do in fact deceive, a substantial portion of the purchasing public. * * * The facts show that it is to the interest of the public that a proceeding to stop the practice be brought. And they show also that the practice constitutes an unfair method of competition as against manufacturers of

[41] Nat'l. Harness Mfg. Assoc. *v.* Fed. Trade Commission, 268 Fed. 705.
[42] Federal Trade Commission *v.* Winsted Hosiery Co., 42 Sup. Ct. Rep. 384.

all wool knit underwear and as against those manufacturers of mixed-wool and cotton underwear who brand their product truthfully. For when misbranded goods attract customers by means of the fraud which they perpetrate, trade is diverted from the producer of truthfully marked goods.

SPECIFIC PERFORMANCE—INJUNCTIONS.

SPECIFIC PERFORMANCE.

"Specific performance may be defined as the actual accomplishment of a contract between parties bound to fulfill it, for a decree for specific performance is nothing more or less than means of compelling a party to do precisely what he ought to have done without being coerced by a court." [43]

May a cooperative association obtain specific performance of its contract with one of its members for the delivery of produce, is a question often asked. It does not permit of a yes or no answer. Specific performance is an equitable remedy. It is fundamental that no one can go into equity to secure specific performance, an injunction, or other equitable relief, where the remedy at law is plain, adequate, and complete. In general, courts of equity will refuse to grant a decree for specific performance if proper compensation for the breach of the contract could be recovered in an action at law. In other words, if full and complete satisfaction could be obtained through the recovery of damages, a court of equity will refuse to decree specific performance. In the case of contracts involving personal property which can be readily purchased in the market, a decree for specific performance will not, as a general rule, be granted. This is on the theory that the injured party could easily acquire personal property like that called for by the contract, and damages would therefore afford a complete remedy.

In a Federal case [44] in which specific performance of a contract for the delivery of oil from wells operated by defendant was decreed it was said:

> It is now well settled that, when the chattels are such that they are not obtainable in the market or can only be obtained at great expense and inconvenience, and the failure to obtain them causes a loss which could not be adequately compensated in an action at law, a court of equity will decree specific performance.

It will be appreciated from what has been said that whether a decree for specific performance will be granted in a given case depends upon the facts.

If the commodity called for by the contract is one which can be obtained only from the party in question, or if it can not be readily

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[43] 25 R. C. L. 203.

[44] Texas Co. *v.* Central Fuel Co., 194 Fed. 1; see also Amer. Smelt. & R. Co. *v.* Bunker Hill & S. Min. & Co., 248 Fed. 172.

purchased in the market, then a decree for specific performance will generally be allowed. In a New Jersey case [45] the plaintiffs, who conducted a canning factory having a capacity of about a million cans of tomatoes, applied for the specific performance of a contract whereby the defendant agreed to sell to them all the tomatoes grown on certain land. The contract was specifically enforced on the ground that the evidence showed that preparations for the season, which lasted but six weeks, had been based on the capacity of the factory and that tomatoes of a similar kind could not be obtained when needed. The court said:

> The business and its needs are extraordinary in that the maintenance of all of the conditions prearranged to secure the pack are a necessity to secure the successful operation of the plant. * * * The objection that to specifically perform the contract personal services are required will not divest the court of its powers to preserve the benefits of the contract. Defendant may be restricted from selling the crop to others, and, if necessary, a receiver can be appointed to harvest the crop.

The remedy of injunction is often employed to supplement a decree for specific performance, especially in cases like those now under discussion.

INJUNCTIONS.

An injunction is an order issued by a court of equity requiring a party to do or to refrain from doing certain acts.[46] Injunctions are usually issued to prevent a threatened injury or to restrain the doing of wrongful acts. They are less frequently granted to require the performance of certain acts. Whether an injunction will be issued depends upon certain well-established equitable principles. It is generally said that the granting of an injunction rests within the sound discretion of the court and that one can not be obtained as a matter of right. However, if the case made out by the applicant for an injunction is perfectly clear, and all the requirements of the law for the issuance of an injunction have been complied with, he is entitled to an injunction as a matter of right.[47]

What right has a cooperative association to enjoin a member from disposing of his produce contrary to the contract entered into with the association? This question, like the one involving specific performance, can not be answered categorically. It is believed that the only case thus far passed upon by a court of last resort in which a cooperative association sought an injunction to restrain one of its members from disposing of produce which he had contracted to deliver to the association is one decided by the Supreme Court of Wash-

[45] Curtice Bros. *v.* Catts, 72 N. J. Eq. 831, 66 Atl. 935.
[46] 22 Cyc. 740.
[47] Sullivan *v.* Jones & L. Steel Co., 208 Pa. St. 540, 57 Atl. 1065, 66 L. R. A. 712.

ington.[48] This case involved a cranberry association which had entered into contracts with growers under which it was made their exclusive sales agent for the sale and marketing of the cranberries grown by them. The contract provided that the grower would not sell any of his cranberries outside of the association. The Supreme Court of Washington affirmed the judgment of the lower court granting an injunction in favor of the association which prevented the member from breaching his contract.

As a rule, when a court grants specific performance, an injunction will be issued to restrain the party from acting contrary to the terms of the order decreeing specific performance. In other words, the remedy of specific performance and the remedy of injunction are both frequently employed in the same case to bring about the result desired. In the Federal case discussed under the head of specific performance, in which specific performance was required of a contract for the delivery of oil, the court also directed that the defendant be enjoined from disposing of the oil in violation of the contract. In other words, the defendant was required to deliver the oil in accordance with the contract and was enjoined from disposing of it in violation thereof. And probably in every case where a court decreed the specific performance of a contract of a cooperative association with one of its members for the delivery of produce, an injunction could be obtained enjoining him from disposing of his produce to other parties. Generally the courts will refuse to decree the specific performance of a contract for personal services or of a contract where the personal element is the dominant one. An extreme illustration of the type of contract referred to is one calling for the painting of a portrait. The personal element might be a factor with a court in refusing to decree the specific performance of a contract of a cooperative association.

Even in cases where the personal element is dominant the courts will, in a proper case, enjoin a party from doing the thing called for by the contract for any other party, but will refuse to require specific performance.

In a Pennsylvania case[49] a baseball player of unusual and extraordinary ability and note who had contracted to play with a certain team, and not to play with any other, was enjoined from playing with any team other than the one with whom he was under contract. There have been many cases analogous in principle with the one just referred to in which similar conclusions were reached.[50] Emphasis in these cases is laid on the fact that the services are extraordinary

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[48] Washington Cranberry Growers' Ass'n. *v.* Moore, (Wash.) 201 Pac. 773; also 204 Pac. 811; in accord Phez *v.* Salem Fruit Union, (Oregon) 201 Pac. 222, 205 Pac. 970.

[49] Philadelphia Ball Club *v.* Lajoie, 202 Pa. St. 210, 51 Atl. 973, 59 L. R. A. 227.

[50] 14 R. C. L. 386.

and unique and that no certain pecuniary standard exists for the measurement of the damages.

In the Washington case in which the cranberry association enjoined the member from disposing of his cranberries to outside parties the court stated that it would not be proper to decree specific performance of the contract, as it would involve continuous supervisory duties by the court. However, it granted an injunction which prevented the member from selling his cranberries outside of the association and which operated to compel their delivery to the association if marketed at all, thus accomplishing indirectly through the remedy of injunction what the court declared could not be done through a decree for specific performance.

In general, an injunction can not be obtained where the remedy at law is adequate, which in most instances means that if damages will compensate the party seeking the injunction his right thereto will be denied. In a case [51] decided by the Supreme Court of the United States the court said:

> It is contended that the injunction should have been refused because there was a complete remedy at law. If the remedy at law is sufficient, equity can not give relief, but it is not enough that there is a remedy at law; it must be plain and adequate, or in other words, as practical and efficient to the ends of justice and its prompt administration as the remedy in equity.

In a case [52] decided by a Federal court in 1921, involving the right to an injunction to restrain the sale of a crop of pineapples and to obtain a decree for specific performance thereof, appears the following:

> It is true that equity will not decree the specific performance of a contract which relates to personality in a case where compensation in damages furnishes a complete and satisfactory remedy. But the bill sets forth special circumstances, the allegations of which it is unnecessary here to repeat, that show that there was no adequate remedy at law.

Instances can easily be conceived of in which produce contracted for by a cooperative association would be vital and necessary to the successful operation of the association. Under such circumstances it is believed that a court would enjoin a member from disposing of his produce outside the association in violation of his contract. Such facts would constitute the "special circumstances" just referred to.

Where a cooperative association is restricted by its charter or the statute under which it is organized to dealing with members, it would seem that this fact would strengthen the case of such a cooperative association seeking to obtain specific performance of its contract with a member for the delivery of produce, or for an injunction to pre-

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[51] Watson *v.* Sutherland, 72 U. S. 74.

[52] Hawaiian Pineapple Co. *v.* Sait, 270 Fed. 749.

vent its breach, or both, inasmuch as the association is prevented from going into the open market to buy the produce involved.

It has been urged in certain cases that specific performance of a contract would not be decreed or an injunction issued to restrain its breach on the ground that the contract involved provided for liquidated damages. This, however, is not the general rule. Although a contract provides for liquidated damages, an injunction will be issued to restrain its breach, or specific performance will be decreed, if the other facts involved warrant such relief, unless the contract shows that damages were to be accepted in lieu of performance of the contract.[53]

Statutes have been passed in many of the States dealing with the remedies of injunction and specific performance, and these should be examined to determine their effect and scope and to ascertain how they have modified or altered the general rules on these subjects.

INCOME TAXES.

Are cooperative associations liable for Federal income taxes, and what must they do to establish their claim to exemption from such taxes? The answers to these questions will be found in the extracts from the Federal revenue act of 1921, and from the regulations issued by the Treasury Department relative to the collection of income taxes under the act, which are here given.

Under the revenue act of 1921, any corporation, and any organization, cooperative or otherwise, which properly is comprehended within the meaning of the term "association," is held to be subject to income tax unless such organization comes within one of the classes of organizations specifically exempted from taxation under section 231 of the act. That section provides in part that the following organizations shall be exempt from taxes under this title:

(10) Farmers' or other mutual hail, cyclone, or fire insurance companies, mutual ditch or irrigation companies, mutual or cooperative telephone companies, or like organizations of a purely local character, the income of which consists solely of assessments, dues, and fees collected from members for the sole purpose of meeting expenses;

(11) Farmers', fruit growers', or like associations, organized and operated as sales agents for the purpose of marketing the products of members and turning back to them the proceeds of sales, less the necessary selling expenses, on the basis of the quantity of produce furnished by them; or organized and operated as purchasing agents for the purpose of purchasing supplies and equipment for the use of members and turning over such supplies and equipment to such members at actual cost, plus necessary expenses.

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[53] Cincinnati-Louisville Theater Co. *v.* Masonic W. & O. H. and I., 272 Fed. 637; Washington Cranberry Growers' Ass'n. *v.* Moore, (Wash.) 201 Pac. 773, 204 Pac. 811.

Article 522 of the regulations referred to reads as follows:

Cooperative Associations: (*a*) Cooperative associations, acting as sales agents for farmers, fruit growers, dairymen, etc. and turning back to them the proceeds of the sales, less the necessary selling expenses, on the basis of the produce furnished by them are exempt from income tax. Thus cooperative dairy companies, which are engaged in collecting milk and disposing of it or the products thereof and distributing the proceeds, less necessary operating expenses, among their members upon the basis of the quantity of milk or of butter fat in the milk furnished by such members, are exempt from the tax. If the proceeds of the business are distributed in any other way than on such a proportionate basis, or if the association deducts more than necessary selling expenses, it does not meet the requirements of the statute and is not exempt. The maintenance of a reasonable reserve for depreciation or possible losses or a reserve required by State statute will not necessarily destroy the exemption. A corporation organized to act as a sales agent for farmers and having a capital stock on which it pays a fixed dividend amounting to the legal rate of interest, all of the capital stock being owned by such farmers, will not for that reason be denied exemption.

(*b*) Cooperative associations organized and operated as purchasing agents for farmers, fruit growers, dairymen, etc., for the purpose of buying supplies and equipment for the use of members and turning over such supplies and equipment to members at actual cost, plus necessary expenses, are also exempt. In order to be exempt under either (*a*) or (*b*) an association must establish that it has no net income for its own account. An association acting both as a sales and a purchasing agent is exempt if as to each of its functions it meets the requirements of the statute.

It will be noted that under the language of subdivision (11), section 231 of the revenue act, that a farmers' cooperative sales or purchasing association would not be entitled to exemption if it did business for nonmembers. Of course, if no profit accrued to an association from its activities no income taxes would be due, regardless of whether or not it did business for nonmembers.

Article 511 of the regulations referred to states how an association may establish its right to exemption. It reads in part as follows:

Proof of exemption.—In order to establish its exemption and thus be relieved of the duty of filing returns of income and paying the tax it is necessary that every organization claiming exemption, except personal service corporations, file an affidavit with the collector of the district in which it is located, showing the character of the organization, the purpose for which it was organized, the sources of its income and its disposition, whether or not any of its income is credited to surplus or may inure to the benefit of any private stockholder or individual, and in general all facts relating to its operations which affect its right to exemption. To such an affidavit should be attached a copy of the charter or articles of incorporation and by-laws of the organization. Upon receipt of the affidavit and other papers by the collector he will inform the organization whether or not it is exempt. If, however, the collector is in doubt as to the taxable status of the organization he will refer the affidavit and accompanying papers to the commissioner for decision. When an organization has established its right to exemption it need not thereafter make a

return of income or any further showing with respect to its status under the law, unless it changes the character of its organization or operations or the purpose for which it was originally created. Collectors will keep a list of all exempt corporations, to the end that they may occasionally inquire into their status and ascertain whether or not they are observing the conditions upon which their exemption is predicated.

In compliance with the section just quoted all associations should submit their cases to the collector of internal revenue for the district in which they are located in order that their claim for an exemption may be passed upon.

UNINCORPORATED ASSOCIATIONS.

Inasmuch as some cooperative associations are unincorporated, a discussion of the legal status of such associations and the rights and liabilities of their members is in order. Such an association may be defined to be a body of persons acting together without a charter but employing to a greater or less extent the forms and methods used by incorporated bodies for the prosecution of the object for which formed.[54]

DIFFER FROM PARTNERSHIPS OR CORPORATIONS.

The liability of members of an unincorporated association to third persons is frequently the same as that of partners, but this is not always true. In the absence of a statutory or contractual provision on the subject the death or withdrawal of a member does not dissolve the association.[55] A partnership, on the contrary, under such circumstances is dissolved by the death or withdrawal of a member.[56] Again, a corporation may sue or be sued in its own name, while at common law, and in the absence of a statute, an unincorporated association can not maintain an action in its own name but must sue in the names of all the members composing it, however numerous they may be.[57] Likewise, such an association in the absence of a statute can not be sued in its society name, but the individual members must be sued.[58] A corporation may take title to property in its own name, but an unincorporated association in the absence of a statute is ordinarily incapable as an organization of taking or holding either real or personal property in its name.[59]

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[54] 5 C. J. 1333.

[55] Burke *v.* Roper, 79 Ala. 138; Lindermann, etc. Co. *v.* Stone Works, 170 Ill. A. 423; Hossack *v.* Dev. Assoc., 244 Ill. 274, 91 N. E. 439.

[56] Scholefield *v.* Eichelberger, 7 Pet. 586.

[57] St. Paul Typothetæ *v.* St. Paul Bookbinders' Union No. 37, 94 Minn. 351, 102 N. W. 725.

[58] Allis-Chalmers Co. *v.* Iron Moulders' Union, 150 Fed. 155.

[59] Philadelphia Baptist Ass'n. *v.* Hart, 4 Wheat. 1, 4 L. ed. 499.

UNINCORPORATED ASSOCIATIONS—HOW FORMED.

Statutes have been passed in some States expressly authorizing individuals to unite as a voluntary association under a distinctive name, but, as a rule, the organization of unincorporated or voluntary associations is done independent of statutes. They are generally formed under the common-law right of contract. Just as A and B may enter into a contract with reference to doing some lawful act, so a larger number may associate for the accomplishment of a lawful object.

Provision may be made for any matter that is the legitimate subject of contract. The qualifications of members may be prescribed, and causes for expulsion may be specified. A constitution is usually adopted which states the objects of the association and other fundamental propositions relative to the organization. By-laws are also usually adopted which prescribe the manner in which the objects of the association are to be attained. The constitution and the by-laws, or either of them, constitute a contract binding all those who agree to them.

In a Michigan case[60] it was said, "The articles of agreement of a benevolent association, whether called a constitution, charter, by-laws, or any other name, constitute a contract between the members which the courts will enforce if not immoral or contrary to public policy or the law of the land." The foregoing was quoted approvingly in a Kansas case[61] involving an antihorse-thief association, and it is believed it states the general rule.[62] It follows that inasmuch as a voluntary association rests on a contract or contracts, the rights or liabilities of members among themselves are to be determined by the contracts involved in accordance with common-law principles as modified or supplemented by statutes; and in the absence of a constitution or by-laws the courts will apply the same legal rules for ascertaining the rights of the parties, weight being given to any usages or customs which may have been followed by the association.[63]

It should be remembered that, in order for a constitution and by-laws, or either of them, to constitute a contract between an association and one claiming or alleged to be a member, he must have agreed to them in some way, either by signing papers containing the constitution and by-laws or by assenting to them in some other way.[64] If one in joining an association signs its constitution and by-laws or assents to them in some other way and thus agrees to be bound by

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[60] Brown *v.* Stoerkel, 74 Mich. 269, 41 N. W. 921, 3 L. R. A. 430.
[61] McLaughlin *v.* Wall, 86 Kans. 45, 119 Pac. 541.
[62] Kalbitzer *v.* Goodhue, 52 W. Va. 435, 44 S. W. 264.
[63] Ostrom *v.* Green, 161 N. Y., 353, 55 N. E. 919.
[64] Austin v. Searing , 16 N. Y. 112, 69 Amer. Dec. 665 and note.

them, he is in no position to complain because he is required to comply with the rules and regulations of the association to which he agreed or because he is expelled from the association in accordance with them.[65]

In a New York case[66] involving the New York Stock Exchange, in which it appeared that a former member had been expelled for cause, the court of appeals of that State said:

> The interest of each member in the property of the association is equal, but it is subject to the constitution and by-laws, which are the basis on which is founded the association. They express the contract by which each member has consented to be bound and which measures his duties, rights, and privileges as such. It seems most clear to me that this constitution and the by-laws derive a binding force from the fact that they are signed by all members and that they are conclusive upon each of them in respect to the regulations of the mode of transaction of his business and of his rights to continue to be a member.

In another case[67] it was said:

> The San Francisco Stock and Exchange Board is a voluntary association. The members had a right to associate themselves upon such terms as they saw fit to prescribe, so long as there was nothing immoral or contrary to public policy or in contravention of the law of the land in the terms and conditions adopted. No man was under any obligation to become a member unless he saw fit to do so, and when he did and subscribed to the constitution and by-laws, thereby accepting and assenting to the conditions prescribed, he acquired just such rights, with such limitations and no others, as the articles of association provided for.

ADMISSION OF MEMBERS.

It has been previously stated that an unincorporated association may prescribe the qualifications of members. It can not be compelled to admit as members persons whom it chooses to exclude.[68] In other words, the whole matter of the admission of members rests with the association. This is well illustrated in the case of Farmers' telephone lines. The question of whether membership can be sold with the farm in such instances has arisen. It is held that an association has the right to control its membership, and a purchaser of a farm merely by virtue of his warranty deed does not become a member of such a telephone company.[69]

MEMBERSHIP NONTRANSFERABLE.

Membership in an unincorporated association is not transferable unless the constitution or by-laws provide that it shall be.[70] The

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[65] State *v.* Seattle Baseball Assn., 61 Wash. 79, 111 Pac. 1055.

[66] Belton *v.* Hatch, 109 N. Y. 593, 17 N. E. 225.

[67] Hyde *v.* Wood, (U. S.) 2 Saw. 655.

[68] Richardson *v.* Francestown Union Cong. Soc., 59 N. H. 187.

[69] Cantrill *v.* Telephone Co. *v.* Fisher, 157 Ia. 203, 138 N. W. 436.

[70] Moore *v.* Telephone Co., 171 Mich. 388, 137 N. W. 241; McMahon *v.* Rauhr, 47 N. Y. 67.

interest of a member in such an association is not devisable or transmissible, and his estate receives nothing therefrom on his death[71] in the absence of a contractual or statutory provision to the contrary.

WHO CONTROL AN ASSOCIATION.

In the absence of an agreement to the contrary, within the scope of the objects for which an association was formed, whether such objects are mentioned in the constitution or other paper defining the objects of the association or necessarily implied therefrom, a majority of the members possess authority to control the action of the association.[72] The majority controls only while it is doing those things for which the association was organized. If it is desired to have the association do something different from that for which it was formed, unanimous consent is necessary.[73]

NOTICE OF MEETINGS.

Where the constitution or by-laws provide how members shall be notified of meetings, they must be followed.[74] In general, all members are entitled to notice of all meetings and of the matters to be considered at such meetings. Where matters of an unusual character are to be considered at a meeting, it is particularly important that the nature of the business be brought to the attention of each member.[75]

UNINCORPORATED ASSOCIATIONS AND THIRD PERSONS.

The liability of the members of an association which is not organized or conducted for profit has been said to rest upon the principles of agency.[76] An illustration will make this clearer. In a Massachusetts case[77] the constitution stated that the association was formed to stimulate interest in the breeding of pigeons and bantams. It gave the board of directors charge of all public exhibitions of the society and required each member to pay an initiation fee and an annual assessment. An exhibition was held, and premiums were offered. The expenses thereof were greater than the receipts. Certain of the members paid the bills. They then brought suit against other members of the association to compel them to contribute their respective proportions of the loss sustained. The court said:

> Mere membership would not bind anybody for any further payment than the initiation fee and annual assessment; but such members as participated in

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[71] Sommers *v.* Reynolds, 103 Mich. 307, 61 N. W. 501; also Mason *v.* Atlanta Fire Co., 70 Ga. 604, 48 Am. R. 585.

[72] 4 Cyc. 310; Goller *v.* Stubenhaus, 134 N. Y. S. 1034.

[73] Abels *v.* McKeen, 18 N. J. Eq. 462.

[74] Kuhl *v.* Meyer, 42 Mo. App. 474.

[75] State *v.* Seattle Baseball Assoc., 61 Wash., 79, 111, Pac. 1055.

[76] 5 C. J. 1363.

[77] Ray *v.* Powers, 134 Mass. 22.

a vote to incur further expenses for an exhibition with premiums, or as assented to be bound by such vote, would be bound thereby.

In other words, only those members were liable who authorized the exhibition with premiums or who later ratified the act of holding such an exhibition. The other members were not liable.

In a Michigan case[78] the members of a building committee of an unincorporated religious society ordered lumber of a lumber dealer for the building of a church. A dispute arose, and the lumber dealer brought suit against the members of the building committee and won. In holding the defendants liable, the court said:

The church organization had no legal existence—it could neither sue nor be sued. The members of the society were not partners. Those of the society who were actually instrumental in incurring the liabilities for it are liable as either principals or agents having no legal principal behind them. Members of the society who either authorized or ratified the transaction are liable, while those who did not are exempt from liability.

All the authorities apparently agree that if the debt or obligation in question was necessarily incurred for the express purpose for which the association was formed each member thereof is liable. In a South Dakota case[79] the following language was used with reference to this matter:

Each member of an unincorporated or voluntary association is liable for the debts thereof incurred during his period of membership and which had been necessarily contracted for the purpose of carrying out the objects for which the association was formed.

Where an unincorporated association is organized and operated for profit the members are generally held liable as partners to third persons. This obligation is imposed by law on the members of such an association, and it is immaterial what the rules of the association provide on the subject of liability.[80] In a California case[81] suit was brought by the plaintiff against the defendant association, which was unincorporated, and certain of its members to recover the sale price of goods purchased by the association for use in its business. The association was composed of 19 members. The defendant recovered an individual judgment against two of the members of the association, and they appealed on the ground that they could not be held individually responsible for the claim of the plaintiff. In affirming the judgment of the lower court the Court of Appeals of California said that the case came within the rule announced in volume 5, Corpus Juris, 1362, 1373, as follows:

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[78] Clark *v.* O'Rourke, 111 Mich. 108, 69 N. W. 147, 66 Amer. St. Rep. 389.

[79] Lynn *v.* Commercial Club of Witten, 41 S. D. 401, 141 N. W. 471; see also Little Rock Furniture Mfg. Co. *v.* Kavanaugh, 111 Ark. 575, 164 S. W. 289; Schumacher *v.* Sumner Tel. Co., 161 Iowa 326, 142 N. W. 1034.

[80] Bennett *v.* Lathrop, 71 Conn. 613, 42 Atl. 634, 71 Am. St. R. 222.

[81] Webster *v.* San Joaquin Fruit, etc., Ass'n., 32 Cal. App. 264, 162 Pac. 654.

While, as between the members of an unincorporated association, each is bound to pay only his numerical proportion of the indebtedness of the concern, yet as against the creditors each member is individually liable for the entire debt, provided, of course, the debt is of such a nature and has been so contracted as to be binding on the association as a whole * * *. An unincorporated association organized for business or profit is in legal effect a mere partnership so far as the liability of its members to third persons is concerned, and accordingly each member is individually liable as a partner for a debt contracted by the association.

It should be borne in mind that the association involved in this case was organized and operated for profit and was not a nonprofit association. This case illustrates one of the serious objections to unincorporated associations, and in turn emphasizes one of the great advantages of an incorporated association in which generally the members are not liable for the debts of the association.

MONEY MUST BE USED FOR PURPOSE FURNISHED.

In a New Jersey case [82] it was said:

"The vote must be for some purpose for which the money was contributed. A majority can not devote the money of the minority or even of a single member to any other purpose without his consent.

The rule that money can be used only for the purpose for which contributed appears settled.[83] In the West Virginia case just cited, a retail butchers' protective association was organized with a constitution which specified the purposes for which money could be used. Through dues paid by the members a fund of $1,800 was accumulated. There were 24 members of the association. At a regular meeting 20 were present, and by a vote of 12 to 8 an order was passed to distribute all of the money in the treasury except $100 among the members. Certain of the members who opposed this use of the money obtained an injunction preventing the distribution of the money, and the Supreme Court of the State held that although a majority of the members present at the meeting had voted in favor of the distribution, yet it could not lawfully be diverted from the purpose for which contributed as set forth in the constitution.

EXPULSION OF MEMBERS.

It was pointed out earlier in this discussion on unincorporated associations that the rights of the members between themselves was a contractual one and that the constitution and by-laws, or either of them, constituted a contract between the members. It follows from this fact that if the constitution or by-laws assented to by the members state causes for expulsion from the association, ordinarily the

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[82] Abels *v.* McKeen, 18 N. J. Eq. 462.
[83] Kalbitzer *v.* Goodhue, 52 W. Va. 435, 44 S. E. 264.

courts would afford no relief if a member were expelled in good faith for such a cause.[84] This is undoubtedly the general rule.[85] However, all rules of the association relative to expulsion must be followed.[86]

The constitution or by-laws of the association may place the entire matter of disciplining, suspending, or expelling members in a committee or like body.[87] Such a provision in the constitution or by-laws, like other legal provisions in such instruments, is binding upon all members assenting to them.

It has been said with reference to unincorporated associations that the "Courts never interfere except to ascertain whether or not the proceeding was pursuant to the rules and laws of the society, whether or not the proceeding was in good faith, and whether or not there was anything in the proceeding in violation of the law of the land."[88] It is believed this states the general rule.

WITHDRAWING OR EXPELLED MEMBERS RECEIVE NOTHING.

In the absence of a contract or statute on the subject, the rule appears to be settled that those who withdraw[89] or are expelled[90] from an unincorporated association are not entitled to compensation for their interest in the association and that they thereby lose all rights in the property of the association.[91] Although a majority of the members of an association withdraw, the right of those who remain to continue the association appears clear, and this right carries with it the right to the proprety of the association.[92] In a Michigan case[93] it was said:

> It has been many times decided that persons who withdraw from a voluntary association are not entitled to any portion of its property, and that those who remain have the right to the property of the association and its use so long as any of the members remain, and clearly withdrawing members ought not to decide the right of those not withdrawing to continue the association.

DISSOLUTION.

In the absence of a statutory or contractual provision to the contrary an unincorporated association can be dissolved only by unani-

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[84] Connolly *v.* Masonic Mutual Benefit Ass'n., 58 Conn. 552, 20 Atl. 671, 9 L. R. A. 428.

[85] See case last cited and note in 9 L. R. A. 428.

[86] Farmer *v.* Board of Trade, 78 Mo. App. 565; Kelley *v.* Grand Circle W. of W., 40 Wash. 693, 82 Pac. 1007.

[87] Harris *v.* Aiken, 76 Kan. 516, 92 Pac. 537.

[88] Kelley *v.* Grand Circle of Woodcraft, 40 Wash. 691, 82 Pac. 1007.

[89] Richardson *v.* Harsha, 22 Okla. 405, 98 Pac. 897; see also Schwartz *v.* Duss. 187 U. S. S.

[90] Missouri Bottlers Ass'n. *v.* Fennerty, 81 Mo. App. 525.

[91] Cases cited above.

[92] McFadden *v.* Murphy, 149 Mass. 341, 21 N. E. 868; Altman *v.* Benz, 27 N. J. Eq. 331.

[93] Walters *v.* Pittsburgh & Lake Angeline Iron Co., 201 Mich. 379, 167 N. W. 834.

mous consent of the members.[94] Upon the dissolution of an unincorporated association, unless otherwise provided by its rules, its property after payments of its debts should be distributed pro rata among those who were members at the time of such dissolution.[95]

APPENDIX.

The suggested form of by-laws which is here given should be modified and altered to suit the individual requirements of the association using them, and, of course, should be considered with reference to the law of the State in which the association is organized.

BY-LAWS OF THE (here insert name of the association).

Article I.—Name.

Section 1. This association, incorporated under the laws of the State of (New York), shall be known as the (Monroe County Fruit Association). Its principal office shall be located in the town of (Hilton, County of Monroe, State of New York).

> Note.—The name should indicate the territory covered and the class of products handled, such as the "Maine Potato Shippers' Exchange" or "Richmond Egg Circle." Some of the State cooperative laws provide that the word "cooperative" shall form part of the name of the organizations incorporated thereunder. As a general rule all associations should be incorporated under the laws of the State in which they are located.

Article II.—Objects.

Section 1. The objects of this association shall be to encourage better and more economical methods of production; to market the products of its members; to secure better results in grading, packing, marketing, and advertising the products of its members; to buy supplies in a cooperative way; to rent, buy, build, own, sell, and control such buildings and other real and personal property as may be needed in the conduct of its operations; to cultivate and develop the cooperative spirit in the community; and to perform any other work which may tend to the betterment of the members and the general benefit of the neighborhood.

> Note.—Make the objects as definite as possible, but it is also well to make them sufficiently broad in scope to cover any future activities of the association. Care should be taken to state the objects in such a way that the activities will be within the limits of the power conferred by the State in which the association is incorporated and in harmony with the articles of association. It may be deemed advisable to set forth in the above paragraph the objects for which the association is incorporated, as stated in its articles of incorporation.

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[94] Sommers *v.* Reynolds, 103 Mich. 307, 61 N. W. 501; Parks *v.* Knickerbocker Trust Co., 122 N. Y. S. 521.

[95] Cases last cited.

Note.—All matter appearing in parenthesis is suggestive merely, and is to be altered to suit the best interests of each individual association.

Article III.—Membership.

Section 1. Any bona fide grower of farm products, in the territory tributary to the shipping points of this association of good character may become a member of the association by agreeing to comply with the requirements of these by-laws.

Sec. 2. Upon entering into such an agreement and the payment of a membership fee of —— dollars, the association shall issue a certificate of membership to the applicant. Such certificate of membership shall not be transferable.

Sec. 3. The violation of these by-laws, or any that may hereafter be adopted, or of any contract entered into by the association with a member, shall constitute a sufficient cause for the expulsion or suspension of such a member from the association. No member shall be expelled from or suspended by, or be deprived of the benefits of the association except by a two-thirds vote of the members present at any annual or special meeting following the mailing of a notice to each member in accordance with these by-laws, specifying that the matter of the expulsion or disciplining of such member is to be voted on at the meeting. The member shall have charges preferred against him at least (10) days in advance of such meeting and shall have an opportunity to present witnesses and to be heard in person and by counsel. Whenever the board of directors, after a hearing, determines that a member has ceased to be a bona fide producer of the products handled by the association, his membership may be terminated and his membership certificate canceled.

> Note.—There may be conditions that make it wise to limit membership to those who have been recommended by the board of directors, or who have received a two-thirds vote of the members present at any meeting. In some localities there are persons who can not work in harmony with their neighbors and for this reason would make undesirable members.

Article IV.—Fiscal Year, Meetings.

Section 1. The fiscal year of the association shall commence (January 1) and end on (the 31st of the following December).

> Note.—The fiscal year should end after the close of one season's business and before the opening of the next. Thus, a grain elevator usually has its fiscal year ending in spring or early summer, when practically all of the work of handling the previous season's business has been finished.

Sec. 2. The annual meeting of the association shall be held at the office of the association, in the town of (Hilton, N. Y.) on the (second Monday in January) of each year, at (10 o'clock a. m.).

> Note.—The annual meeting should be held shortly after the beginning of the fiscal year. Previous to this meeting all transactions of the fiscal year just ended should be closed, the books audited and the annual reports of the officers prepared.

Sec. 3. Special meetings may be called at any time by the president. He shall call such meetings whenever (10) members shall so request in writing.

Sec. 4. Notice of the annual meeting shall be mailed by the secretary to each member at least (one week) previous to the date of the meeting and such notice shall be published in a local newspaper not less than (one week) previous to the date of meeting. At least (five) days before the date of any special meeting the secretary shall mail notice of such meeting to each member, which shall state the nature of the business to be transacted at such meeting.

Article V.—Quorum.

Section 1. (One-fifth) of the members in good standing shall constitute a quorum for the transaction of business at any meeting.

> Note.—When the organization is small and compact, the proportion required for a quorum may be larger than in a large organization whose members are scattered over a wide territory.

Article VI.—Directors and Officers.

Section 1. The board of directors of this asssociation shall consist of (seven) members, who shall be divided into three classes. After the adoption of these by-laws, the members shall elect from among themselves (three) directors of the first class for a term of one year, (two) directors of the second class for a term of two years, and (two) directors of the third class for a term of three years. At the expiration of the terms of the directors so elected their successors shall be elected in like manner, for terms of three years. Directors shall hold office until their successors have been elected and qualified and have entered upon the discharge of their duties.

> Note.—In some States the corporation laws stipulate the number of directors and officers an association shall have. The plan of having each shipping station or district represented on the board of directors helps to prevent jealousies between the various districts and strengthens the confidence of those attempting to cooperate. Some object to a director holding office for more than one year, claiming that the board might become so objectionable to the members that it would be desirable to elect an entirely new board at the annual meeting. However, there are many advantages in keeping some experienced directors on each board. In case the entire board should go contrary to the wishes of the members, the recall of each director could be effected under Section 6 of this article.

Sec. 2. The board of directors shall meet within (10) days after the first election, and after each annual election, and shall elect by ballot a president and a vice-president from among themselves, and a secretary-treasurer (or a secretary and a treasurer) who may or may not be a member of the association. They shall also choose three auditors from the members who are not directors, officers, agents, or employees of the association. Such officers and auditors shall hold office for one year or until their successors are duly elected and qualified.

> Note.—Some organizations desire to have someone outside the membership act as secretary or treasurer, as for instance a local banker. When such an arrangement is desired it should be provided for in the by-laws.

Sec. 3. Any vacancy in the board of directors shall be filled for the unexpired term by the remaining members of the board of directors, and directors so chosen shall hold office until their successors shall have been elected at a regular or called meeting of the association.

Sec. 4. (Four) members of the board of directors shall constitute a quorum at any meeting of the board of directors.

Sec. 5. (The compensation, if any, of the board of directors and the officers shall be determined by the members of the association at a regular or called meeting of the association.)

Sec. 6. Any director or officer of the association may, for cause, at any annual or at any special meeting called for the purpose, at which a majority of the members shall be present, be removed from office by vote of not less than two-thirds of the members present. Such director or officer shall be in-

formed in writing of the charges against him at least (10) days before such meeting and at such meeting shall have an opportunity to present witnesses and to be heard in person and by counsel in regard thereto.

NOTE.—In some cases, especially when the board of directors is large, it is desirable to have an executive committee. Such a committee can be made of the officers and one or two members of the board.

ARTICLE VII.—DUTIES OF THE DIRECTORS.

SECTION 1. The board of directors shall manage the business and conduct the affairs of the association and shall make the necessary rules and regulations, not inconsistent with law or with these by-laws, for the management of the business and the guidance of the officers, employees, and agents of the association.

SEC. 2. The board of directors may employ a business manager, fix his compensation and dismiss him for cause. He shall have charge of the business of the association under the direction of the board of directors.

SEC. 3. The board of directors shall require the treasurer and all other officers, agents, and employees charged by the association with responsibility for the custody of any of its funds or property to give bond with sufficient surety for the faithful performance of their official duties, which bond shall be paid for by the association.

SEC. 4. The board of directors shall meet on the (first Saturday) of each month at the office of the association in the town of (Hilton, N. Y.). Special meetings of the board shall be held upon call of the president or upon written request of (three) members of the board.

ARTICLE XIII.—DUTIES OF OFFICERS.

SECTION 1. The president shall—

a. Preside over all meetings of the association and of the board of directors.

b. Sign as president (with the secretary-treasurer) all checks, notes, deeds, and other instruments on behalf of the association.

c. Call special meetings of the association and of the board of directors and perform all acts and duties usually required of an executive and presiding officer.

SEC. 2. In the absence or disability of the president, the vice president shall preside and perform the duties of the president.

SEC. 3. The (secretary-treasurer) shall—

a. Keep a complete record of all meetings of the association and of the board of directors.

b. Sign (as secretary-treasurer), with the president, all checks, notes, deeds, and other instruments on behalf of the association.

c. Serve all notices required by law and by these by-laws.

d. Receive and disburse all funds and be the custodian of all the property of this association.

e. Keep a complete record of all business of the association and make a full report of all matters and business pertaining to his office to the members at their annual meeting and make all reports required by law.

f. Perform such other duties as may be required of him by the association or the board of directors.

NOTE.—When the offices of the secretary and treasurer are separate, the duties of each should be given in different sections.

Article IX.—Duties and Powers of the Manager.

Section 1. Under the direction of the board of directors, the manager shall employ and discharge all employees, agents, and laborers. He shall secure information as to crop and market conditions, and furnish the same to the members on request. He shall encourage the production of the best varieties of products demanded by the trade. He shall acquaint each member as far as practicable with the form and manner in which his products shall be prepared for market. He shall have charge of the grading, packing, and inspection of all products handled by the association, and shall have control of the brands and labels and their use on such products, in accordance with the rules of the association. Subject to the terms of the contracts made by the members with the association for the marketing of their products, the order of the board of directors, and the by-laws and rules of the association, the manager shall have entire charge of the sale and marketing of such products.

Note.—The manager is the most important officer, and the success or failure of the association will to a large degree depend upon him; hence his power must be limited as little as possible. He can not be held responsible if he is to be dictated to at will by each member or if the officers are to meddle constantly with his work. This does not imply that the manager should be a dictator. He should take the suggestions of the officers and members and from them and his own experience construct a business plan. Whenever a manager loses the confidence of the members, he should be replaced with a manager who possesses that confidence. The duties of a manager differ with the different forms of organization and kinds of business. Therefore the duties here outlined must be considered as suggestive. Each association should redraft this provision to suit its purposes. Organizations like creameries and cheese factories may find it advisable to insert an article relating to the duties of the butter maker or cheese maker, as in such organizations the duties of the manager usually are more limited.

Article X.—Membership Fee and Finance.

Section 1. Each member shall pay in advance to the association a membership fee of ($5).

Sec. 2. At the time of uniting with the association or at any time thereafter when called upon by the board of directors each member shall loan an amount to be fixed by the board, not less than ($10) nor more than ($100), in cash to the association to be used in building warehouses or other necessary buildings and the lease or purchase of lands therefor or in securing necessary equipment.

Sec. 3. Such loans shall draw interest at the rate of (6) per cent per annum.

Sec. 4. Such loans shall be repaid from a special fund created by levying a percentage assessment on the produce sold and supplies bought through the association, the amount of such percentage to be fixed by the board of directors, which amount shall be sufficient to pay (one-fifth) of the entire loan and the interest thereon in each year.

Sec. 5. At the end of each fiscal year each member shall receive a certificate showing the amount of money which he has contributed that year to the special loan fund. During the life of the association, or until this by-law is changed, the special assessments shall continue and the holders of such certificates issued in previous fiscal years, out of the proceeds arising therefrom, shall be paid the amounts due thereon.

Note.—This article suggests a method which nonstock organizations may employ to secure the capital necessary to build warehouses or purchase equipment. Organizations which require only a small outlay for equipment can provide the necessary capital through the membership fee.

Article XI.—Emergency Capital.

Section 1. At the time of uniting with the association, or any time thereafter when called upon by the board of directors, each member, in consideration of the maintenance and operation of the association, shall give a negotiable promissory note, payable on demand to the order of the association. Such note shall be for the sum of ($25) and an additional ($1) for each acre of land farmed by the member, the products of which are to be marketed through the association. But in no case shall this note be for less than ($35).

Sec. 2. Such note shall be the property of the association for the purpose of being pledged by the board of directors as collateral security for any loan that may be necessary in the conduct of the association's business and also for the purpose of securing the payment of any debt or claim due by the member to the association. And such note shall retain its negotiable character without reference to the date of its negotiation.

> Note.—This article is intended to supply capital which is needed only for short periods; for example, during the harvesting and shipping period and other periods when a temporary supply of money is required. The exact legal status of notes of this character in the State where they are to be employed should be ascertained.

Article XII.—Grading and Inspecting.

Section 1. All products grown by the members for sale through the association shall either be graded and packed on the growers' premises, in accordance with the rules of the association, subject to such inspection as may be established by the board of directors, or shall be delivered to the association, as directed by the manager, in prime conditions for grading, packing, and shipping.

Sec. 2. All produce offered for shipment shall be inspected before shipment. If any produce is not of good quality and in good condition for shipping, such produce shall be sorted and prepared for shipment at the expense of the owner.

Sec. 3. All brands, labels, trade-marks, and the like established by the association shall be registered and become its property, and they shall be attached only to such grades as shall be approved by the board of directors.

> Note.—The nature of organization and the kind of business engaged in should be kept in mind, and the grading and inspecting rules given in this article adapted to fit the requirements of the organization and the products handled.

Article XIII.—Contracts and Agreements.

Section 1. Every member of this association shall enter into a contract with the association in the form required by the board of directors, subject to the following provisions:

(*a*) That the member, by said contract, appoints the (Monroe County Cooperative Fruit Association) his sales agent to sell all products grown by him for sale, or such part thereof as shall be specified in the contract, and binds himself to deliver such products to the (Monroe County Cooperative Fruit Association) for sale at such time and place as the rules fixed by the board of directors of the association may direct.

(*b*) That said contract shall run continuously unless canceled by the member on (April 1) of any year by giving written notice to that effect to the association at least (30) days prior to said date and by delivering his copy of the contract

to the association on or before that date. Such cancellation shall be subject to any indebtedness due from him to the association.

NOTE.—No cooperative association should attempt to do business without definite contracts with its members. The manager can not be expected to work to advantage unless he has definite knowledge of the quantity and kinds of products he is expected to market, and this knowledge should be in his possession early in the season. Unless a member is willing to bind himself under an enforceable contract he can not expect his association to transact business to his advantage.

ARTICLE XIV.—DUTIES AND RIGHTS OF MEMBERS.

SECTION 1. A member shall have the right to give away or retain for his own use such of his farm products as he may wish, but he shall not sell any products contracted to the association to an outside party, except products offered to and rejected by the association.

SEC. 2. Any member who receives an offer for his farm products which is greater than the price presently obtainable through the association may submit this offer to the manager. If deemed advisable, the manager may authorize the member to accept the offer, but payment for the products shall be made to the association. Products sold in this manner shall bear their proportional share of the association's expenses, and settlement therefor shall be made to the member in accordance with Article XVI, section 2, of these by-laws.

SEC. 3. Each member shall have a number or mark which shall be permanently stamped on every sack, box, barrel, crate, basket, or other container, packed by him or under his direction, for shipment through the association. Any loss occasioned by improper packing or grading shall be charged to the member whose mark is found on said package.

NOTE.—Products packed on the growers' premises should be inspected by an association inspector. The inspector must be accountable only to the association. His private mark should be placed upon each package he inspects, and he should be held jointly responsible with the grower for the grade and condition of the pack as disclosed in the market.

SEC. 4. On or before (April 1) of each year each member shall report to the association the acreage of products to be grown by him that year for sale through the association. During the growing season each member shall furnish such information concerning the crops contracted to the association as may be required by the manager.

NOTE.—This section is intended for organizations handling perishable products, such as fruit and vegetables, where it is important to know the volume of business to be handled.

SEC. 5. Each member of the association shall have only one vote. No member shall be allowed a vote so long as any past-due debts or obligations owing by him to the association remain unpaid. Voting by proxy shall not be permitted. Except in case of the removal of a director or officer, as provided in Article VI, Section 6, of these by-laws, absent members may vote on specific questions by ballots transmitted to the secretary of the association by registered mail, and such ballots shall be counted only in the meeting at the time at which such vote is taken.

NOTE.—In a stock company, which is organized to earn profits on the money invested in the business, a member generally votes in proportion to the number of shares he holds, but a true coopera-

tive association is based on the individual member, a number of whom unite to do something in which they have a common interest. In the former, money controls; in the latter, men. While there may be cases where the voting power of the members may be made in proportion to the acreage of their products, it will generally be found that any attempt to vary the voting power of members will be unwise. The practice of allowing a member to collect the proxies of absent members and vote the same tends to give a single member influence in the association which is too dangerous to be allowed.

In some of the largest nonprofit cooperative associations it has been felt that it was neither fair nor wise to demand that the large-producing member should be held to the same vote as a small-producing member, as their responsibility and interest are so unequal. In such a case the voting power of members may be proportioned according to the amount of their products or acreage handled through the association.

SEC. 6. Any member may withdraw from the association at any time during the month of January of any year, but such withdrawal shall not affect any right or lien which the association has against the retiring member or his property until his indebtedness to the association is fully paid. Any member having a grievance or complaint against the association may appeal to the board of directors (or to the members at any regular or called meeting).

NOTE.—The time of withdrawal should be so fixed as to take effect some time between the close of one season's business and the opening of the next. To permit a member to withdraw during a busy marketing season will result in confusion and may seriously handicap the manager in filling his contract.

The laws of several of the States providing for the incorporation of cooperative associations require that the by-laws shall provide the manner of ascertaining a member's interest upon his death, withdrawal, or expulsion. This subject should be investigated and, if required, provision made therefor. The following by-law is suggested when found necessary:

On the death, withdrawal, or expulsion of a member his interest in the association shall be conclusively ascertained and determined by appraisal by the board of directors, and the association shall pay the amount thus ascertained to the member or his legal representative within one year from the date of appraisal.

ARTICLE XV.—INDEBTEDNESS, MEMBERSHIP LIABILITY.

SECTION 1. The amount of indebtedness which may be incurred by or on behalf of this association shall at no time exceed ($20,000).

ARTICLE XVI.—EXPENSES AND PAYMENTS.

SECTION 1. The expense of operating the association shall be met by a percentage charge laid upon returns for produce sold, or by a uniform fixed price per package; and upon supplies purchased, the amount of such charge to be fixed by the board of directors.

SEC. 2. The association may pool or mingle the products of each member with products of like quality, variety, and grade delivered by other members. The net returns from the sale of such products less such costs, advances, reserves, and charges as are provided for in these by-laws and the rules prescribed by the board of directors, shall be credited and paid to each member in proportion to the quantity of such products shipped by him through the association, and on the basis of the average price received for such products of like quality, variety,

and grade during such period or periods as the board of directors from time to time may determine.

NOTE.—It is important that an average price should be paid for products of the same grade shipped during a specified period. In this way inequalities and dissatisfaction are avoided, and the association is better able to serve the interests of the entire membership.

ARTICLE XVII.—COOPERATIVE PURCHASE OF SUPPLIES.

SECTION 1. All merchandise purchased by the association for any member shall be paid for in cash by the member ordering such supplies at the time the order is placed.

NOTE.—Without such a provision an organization purchasing supplies for its members may find that some of the members will refuse to take supplies ordered or else will not pay promptly. A cooperative organization should extend credit to no one unless it is amply secured.

SEC. 2. If local dealers handle the supplies desired, they shall be given an opportunity to bid on the order before it is placed with an outside agency.

NOTE.—In the cooperative plan of buying farm supplies the local dealer should be given consideration and an opportunity to submit terms and prices.

ARTICLE XVIII.—SAVINGS AND DAMAGES.

SECTION 1. After the season's expenses are paid and a proper sum set aside to cover the depreciation of the association's property and provision is made for a reserve fund to be fixed by the board of directors, the balance of the season's returns on products sold shall be divided among members and nonmember patrons, if any, in proportion to the value of their products sold through the association, and the balance of the season's savings on supplies purchased shall be divided in like manner. In the case of a nonmember patron, any part of such sums of money may be applied, with his consent, to the payment of membership fees and dues for him; and, if so applied, when such fees and dues are fully paid a membership certificate shall be issued to him. When any nonmember offers his products and the association accepts them for sale, such offer and acceptance shall be deemed an application for membership, if the nonmember agrees that it shall be so considered.

SEC. 2. Any member who fails or refuses to deliver his fruits and vegetables to the association in accordance with the contract entered into by him with the association shall pay to the association the sum of_____ for each_____of_____not delivered by him to compensate the association for its expenditures in providing and maintainig for him the machinery, equipment, facilities, personal services, and information necessary to market his crop. And in addition thereto, he shall be liable to the association for all damages suffered by it as a result of the breach of the contract. All contracts entered into by the association with members for the delivery of produce contemplate the delivery of such produce and not the payment of compensation in lieu thereof.

NOTE.—Many organizations have failed because members were bound only by a "gentleman's agreement," which is totally inadequate for a stable and enduring organization. The laws of the State should be studied to ascertain the status of a provision of this kind.

Article XIX.—Accounts and Auditing.

Section 1. This association shall install a standard system of accounts and provide other accounting appurtenances that may be necessary to conduct the business in a safe and orderly manner.

> Note.—The Bureau of Agricultural Economics has devised systems of accounts for several types of cooperative business, such as grain elevators, fruit organizations, creameries, live-stock shipping associations, and stores. Information in regard to systems of accounts may be obtained by writing to the Bureau of Agricultural Economics, U. S. Department of Agriculture.

Sec. 2. The books and business of the association shall be audited quarterly by the auditors selected from the membership. A complete annual audit shall be made by a competent accountant previous to the date of each annual meeting, at which meeting his report shall be presented in full. Special audits shall be made upon order of the board of directors or upon a majority vote of the members at any regular or called meeting.

Sec. 3. This association shall endeavor to cooperate with other farmers' cooperative associations in this locality in securing the services of a competent accountant for its annual audit.

> Note.—While small associations may not feel the need of such a strict system of investigating their accounts, it will pay to have this work done often and thoroughly. If the business of the association is being conducted carelessly, frequent audits will make this fact known, and better methods may be adopted before any great loss occurs. An audit by an expert accountant gives the members confidence in the business methods of the manager and directors.

Article XX.—Amendments.

Section 1. These by-laws may be amended at any meeting by a two-thirds vote in the affirmative of the members present, provided that notice of the proposed amendment is included in the call for said meeting.

ASSOCIATIONS FORMED WITH CAPITAL STOCK.

Organizations which are formed with capital stock should replace Articles III and X of the suggested by-laws for organizations without capital stock with the following articles:

Article III.—Membership.

Section 1. Any (bona fide) grower of farm products in any territory tributary to the shipping points of this association may become a member of the association by agreeing to comply with the requirements of these by-laws and purchasing at least one share of capital stock of the association.

> Note.—See note following Article III of the by-laws for organizations without capital stock.

Article X.—Capital Stock.

Section 1. The capital stock of this association shall be $5,000 divided into 500 shares of $10 each.

Sec. 2. No member shall hold more than 10 per cent of the capital stock of the association.

SEC. 3. No stock shall be issued or delivered by the association to any subscriber until he has paid the full price therefor.

SEC. 4. Transfers of shares will be made upon the books of the association only when the stockholder is free from indebtedness to the association.

SEC. 5. Whenever any stockholder desires to sell his stock he shall first offer it to the association for purchase by it or by a person or persons designated by the board of directors of the association at a price to be conclusively determined by the board of directors. In the event the stock is not purchased by the association, or by a person or persons designated as aforesaid, within 30 days after the receipt of a written notice by the association offering the stock for sale, then the stockholder may sell the stock to any person engaged in the production of agricultural products. This restriction on the transfer of stock shall be printed on every certificate of stock.

SEC. 6. If any member shall by purchase or by the operation of law come into possession of more than ——— shares of the capital stock of this association, the board of directors may elect to purchase, and such member shall then sell to the association such excess shares at a price to be conclusively determined by the board of directors, plus any dividends or refunds due and unpaid. Also, in the event of the death or disability of the owner of any shares of stock in this association such shares of stock may be purchased by the association and shall, in the event the board of directors elects to purchase them, be sold by the legal representatives of such owner to the association at a price to be conclusively determined by the board of directors, plus any dividends or refunds due and unpaid.

NOTE.—The law of the State in which the association is organized should be carefully examined to determine the status of sections 4, 5, and 6 of this article. In general, provision should be made for them in the charter in order that they may be legal.

FORM OF CONTRACT.

The form of contract which is here given is simply suggestive and is designed to serve only as a guide in the preparation of a contract for use by an association, and, of course, like the form of by-laws, should be considered with respect to the law of the State where the association is to operate.

THE _____ COOPERATIVE ASSOCIATION.

STANDARD FORM OF CROP CONTRACT.

THIS AGREEMENT, made and entered into at _____ on this _____ day of _____, A. D. 19__, between the _____ Association, formed under the laws of the State of _____, having its principal place of business at _____, in the said State (hereinafter referred to as the association), and _____, a grower of (fruit and vegetables) of _____, county of _____, State of _____ (hereinafter referred to as the grower), witnesseth:

That for and in consideration of the expenses to be incurred by the association in providing means and facilities for handling, storing, and marketing (fruits and vegetables), including the expense of locating, organizing, and es-

tablishing markets, and in further consideration of the mutual obligations and promises of the respective parties hereto, it is hereby agreed as follows:

1. That the grower appoints said association his agent, and the association hereby agrees to act as such for the purpose of handling, packing, storing, and marketing all the (fruits and vegetables) which shall be grown for shipment and sale by the grower or for him, whether as landlord or tenant or otherwise, in the county of _____, State of _____, and that he will harvest and will deliver all his marketable (fruits and vegetables) at the association's shipping staton at _____, in said State, in such quantities and conditions and at such times as the rules fixed by the board of directors of the association may direct, during the year 19__, and every year thereafter continually. On or before (April 1) of each year the grower shall report to the association the acreage to be grown by him during that year of (fruits and vegetables) covered by this contract. During the growing season the grower shall also furnish such information concerning said (fruits and vegetables) as may be requested by the manager.

2. That either party may cancel this contract on the first day of (April)[96] of any year by giving notice in writing to that effect to the other party at least thirty (30) days prior to said date. Upon such notice the grower shall, prior to said first day of (April), pay or satisfactorily secure any indebtedness then due from him to the association and deliver his copy of said contract to the association; such cancellation shall not affect any incompleted sales or transactions between the parties hereto, nor release either from any indebtedness then unpaid or thereafter accruing under this contract, nor relieve the grower from his obligation to sell through the association, nor the association of its obligation to handle all the (fruits and vegetables) described in section 1 which were grown during the preceding season. It is expressly agreed that this contract shall be binding upon the legal representatives of the grower.

3. That harvesting, grading, inspecting, packing, storing, and shipping of the (fruits and vegetables) shall be done in accordance with the by-laws and rules of the association.

4. That all (fruits and vegetables) delivered by the grower may be marketed in assorted lots or with other (fruits and vegetables) of like quality, variety, and grade, and the net proceeds of any or all of such shipments may be prorated during such period or periods as the board of directors from time to time may determine.

5. That the association shall have a lien upon the (fruits and vegetables) hereby contracted by the grower to be delivered to the association for any indebtedness of any kind owing by him to the association, and any such indebtedness shall be deducted out of the net proceeds of the sale of such (fruits and vegetables).

6. That the grower will not sell or otherwise dispose of his (fruits and vegetables) covered by this contract to any purchaser except through the association unless such (fruits and vegetables) have been rejected by the association. In case the grower is offered a price in excess of the price presently obtainable by the association he may submit such offer to the manager. If deemed advisable the manager may authorize the member to accept the offer, but payment for the product shall be made to the association.

7. That the (fruits and vegetables) covered by this contract shall be marketed by the association wherever a market may be found which in its judg-

[96] This date should, if possible, be after the closing of one season's business and before the opening of the next.

ment and in accordance with its by-laws and rules shall justify such marketing. The association shall not be liable for any damage that may be sustained through act of God or public enemy, or accidents in shipment or storage, or unavoidable failure to secure suitable storage or markets for the proper handling and storing and marketing of said (fruits and vegetables). Any loss occasioned by the grower shall be borne by him.

8. That the grower will pay the association its regular charges for its services, including handling, storing, shipping, and marketing, which charges are to be fixed by the board of directors of the association, and which shall be in amount sufficient to pay all expenses of rendering such service, including the overhead expenses of the association. The grower gives the association the right to deduct the amount necessary to cover such charges from the returns received from his (fruits and vegetables).

9. Any member who fails or refuses to deliver his (fruits and vegetables) to the association in accordance with this agreement shall pay to the association the sum of _____ for each _____ of _____ not delivered by him to compensate the association for its expenditures in providing and maintaining for him the machinery, equipment, facilities, personal service, and information necessary to market his crop. And, in addition thereto, the grower shall be liable to the association for all damages suffered by it as a result of the breach of the contract. This contract contemplates the delivery of the (fruits and vegetables) covered thereby, and not the payment of compensation in lieu thereof.

10. That the association shall have power to borrow money in its name and on its own account on the (fruits and vegetables) consigned to it, products manufactured therefrom, or on any accounts of the sale thereof, or any drafts, bills of lading, bills of exchange, notes, acceptances, or any commercial paper held by it, and to pledge in its own name and on its own account drafts, bills of lading, bills of exchange, notes, acceptances, or any commercial paper as collateral.

11. That there are no oral or any other conditions, promises, covenants, representations, or inducements in addition to, or at variance with any terms hereof, and that this agreement represents the voluntary and clear understanding of both parties fully and completely.

In witness whereof the said parties have executed this contract in duplicate.

_____,
Grower.

_____, Cooperative Association.
By _____,
President.

Attest:

_____.
Secretary.

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UNITED STATES DEPARTMENT OF AGRICULTURE

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Washington, D. C. PROFESSIONAL PAPER December 4, 1922

THE LEAD-CABLE BORER OR "SHORT-CIRCUIT BEETLE" IN CALIFORNIA.[1]

By H. E. Burke,[2] *Entomologist*, R. D. Hartman, *Field Superintendent in Insect Control*, and T. E. Snyder, *Entomologist, Forest Insect Investigations, Bureau of Entomology.*

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REVIEW OF INJURY TO METALS BY BORING INSECTS THROUGHOUT THE WORLD.

From time to time articles appear in technical journals throughout the world describing injury to metal by boring insects, such injury occurring most commonly in the Tropics. Often the press makes

[1] *Scobicia declivis* Lec.; order Coleoptera, family Bostrichidae.

[2] The authors' names are arranged alphabetically; R. D. Hartman should be credited with the biological studies and most of the experimental tests in California.

much of these accounts, usually in a jocular vein; thus "Bugs" Baer proposed to utilize the lead borer in warfare to eat the helmets off the heads of enemy soldiers, who would then catch cold, influenza, and quinsy from standing bareheaded in a damp trench! With few exceptions the cases recorded are merely accidental and result from the fact that metal blocks the exit of an emerging adult or occurs in the path of a burrowing larva, and they do not constitute direct attacks. In some cases, however, the insects make a direct attack and the resulting injury is serious.

Insects of many different orders are involved. Beetles, or Coleoptera, however, are the more common culprits and include the most injurious species. The families represented are Anobiidae (*15*),[3] Anthribidae (*30*), Bostrichidae (*8*, *30*, *36*, *39*, *41*, *43*, *45*, *48*, *49*, *51*, *52*, *54*), Buprestidae (*47*), Bruchidae, Cerambycidae (*3*, *5*, *9*, *11*, *20*, *21*, *25*, *36*), Curculionidae (*30*), Dermestidae (*4*, *9*, *54*), Lyctidae, Ptinidae (*23*, *31*, *33*, *34*), and Tenebrionidae (*24*). Insects of other orders which have been recorded as injuring metal are members of the family Cossidae in the Lepidoptera (*10*, *14*, *30*), termites or white ants (Isoptera) (*27*, *28*, *37*, *40*, *50*), and the horntail Sirex (*6*, *17*, *18*, *36*, *44*, *55*) and a wasp in the Hymenoptera (*30*, *32*).

Lead is the metal most commonly injured (*1*, *13*, *19*, *35*, *43*, *44*, *45*, *46*, *49*, *53*), such varieties of products having been attacked as lead bullets and cartridges (*7*, *16*, *17*, *18*, *26*), lead (and also tin) roofing (*3*, *5*, *9*, *10*), lead rain gutters, lead stereotype plates (*8*), lead piping for both water and gas (*25*, *47*, *64*, *66*), lead lining of vats, tanks, and cisterns (*15*), the sheet-lead protection for beehives, lead crucibles, lead fuses (*54*), telephone batteries, the lead sheathing of aerial telephone cables (*32*, *38–43*, *48*, *49*, *51*, *52*, *54*), high-tension cables, and lead cables in underground wooden-cased conduits (*27*, *28*, *37*, *40*, *50*), in Australia, Central America, and the United States. A rather interesting type of injury is that to tubular lead telephone fuses (*54*). There is an extensive bibliography in many languages. A portion of this literature is cited under "Insects attacking or penetrating metals," p. 42. Other metals attacked by insects are tin, zinc (actually found in the stomach of the borer) (*21*), silver-plate service (*23*, *31*, *33*, *34*), (quicksilver) lining of mirrors (both in Europe and the United States), and the gilding of chandeliers. Minerals (*4*, *9*), shell or horn, other hard substances (*22*), and inorganic matter (*2*) are also penetrated by insects.

The cosmopolitan ptinid beetle *Niptus hololeucus* Fald. is not only injurious to the quicksilver lining of the backs of mirrors, but also to silver-plate service stored in closets and the gilt on chandeliers.

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[3] Numbers in parentheses (italics) refer to "Literature cited," p. 42. It should be noted that many records referred to in the text have not been published elsewhere.

Another ptinid beetle, *Mezium americanum* Lap., also damages gilded chandeliers, according to Dr. E. A. Schwarz, of the Bureau of Entomology.

A type of injury which occurs fairly commonly is that caused by larder beetles (species of *Dermestes*) to lead telephone fuses.

The most common, extensive, and serious injury to metal by insects, however, is that caused to the lead sheathing of aerial cables; such damage occurs throughout the world and is caused by a great variety of insects (*30*), but the most prevalent and serious injury is that caused by bostrichid beetles.

INJURY TO LEAD FUSES BY INSECTS.

The purpose of the tubular lead telephone fuse is to protect the telephone equipment from heavy currents; the action of the fuse is to melt or "blow," thus "grounding" the objectionably heavy current

FIG. 1.—The "hide beetle" (*Dermestes vulpinus*): Adult, enlarged 4 times; at left, mandible, enlarged 20 times.

FIG. 2.—Typical dermestid larva (larva of *Dermestes nidum avium*). Greatly enlarged. (After A. Böving.)

and preventing further damage. These fuses are made from paper or fiber treated with zinc chlorid and hardened by subjection to considerable pressure. The wire or tape used in these fuses is chiefly lead, although hardened with the addition of a small percentage of another hardening metal such as tin or antimony. Suitable terminals are provided at the ends of the tube for terminating the fusible conductor. By eating through the lead the insects make it necessary to replace the fuse just as if it had been operated in its regular

function and blown out. The chemically treated fiber tube is not attacked. Both adults and larvæ of the dermestid "hide beetle" (*Dermestes vulpinus* Fab., Fig. 1), have been found in these tubular fuses. The larvæ (Fig. 2) of this scavenger beetle probably enter the fuse to pupate; wood is frequently damaged by larvæ boring through it to form pupal cells; indeed, even asbestos is so penetrated (*4*).

In May, 1910, the Chesapeake & Potomac Telephone & Telegraph Co. reported damage, caused by insects determined as *Dermestes vulpinus*, to fuses in a box at Baltimore, Md. A similar case of this beetle eating fuses mounted in boxes on telephone poles was reported in June, 1910, at St. Louis, Mo., by the American Telephone & Telegraph Co.

The Chicago Telephone Co. reported several years ago damage to a telephone fuse in the Chicago stockyards. The fuse had been cut. An adult and two larvæ of *Dermestes vulpinus* were found in the fuse. The fuse wire had been bored through bit by bit. The adult was an unusually small specimen. The location of this damage in the stockyards is significant, since this insect normally damages hides, etc.

Dr. Wm. Lewis Culpepper, of Syracuse, N. Y., reported in March, 1916, that an insect, determined as *Dermestes vulpinus*, was found eating and destroying the battery in a telephone; *i. e.*, "dry cells" with the shell made of zinc.

DAMAGE TO LEAD SHEATHING OF AERIAL CABLES BY SCOBICIA DECLIVIS LEC.

Character of Damage.

Damage to the lead sheathing of aerial telephone cables consists of perfectly round holes about 2.5 millimeters (0.1 inch) in diameter which extend through the lead sheathing from the outer surface to the paper insulation of the wires within. (Pl. VI, Fig. 3; Text Fig. 3.) Cables of various diameters are attacked. In practically every case the hole is made through the lower side of the sheath close to where the suspending ring or metal or marline hanger supports the cable. In a few cases the damage is done where the cable has been scarred or roughened or where an upright cable has been fastened to the poles by clamps. In a number of cases where attempts had been made on the sheathing the work was abandoned before the sheathing was penetrated. In cases where the sheathing is penetrated, moisture is very readily drawn in to the wires and the entire supply of electric current may be short-circuited. If the hole happens to be in the proper location a great deal of moisture enters and the cable may be ruined for 15 to 20 feet. Particularly in case of slack cable or those on grades the moisture sometimes penetrates and soaks the insulation for long distances. This necessitates cutting out the cable, splicing

and insulating the wires, and resheathing, which in a 600-pair cable means considerable skilled labor.[4]

Most of the damage is probably done from June to August, when the beetles are emerging in large numbers. The injury is not apparent, however, until later, after the rains, when the water soaks through and causes a short circuit. Thus usually all the "troubles" come at once.

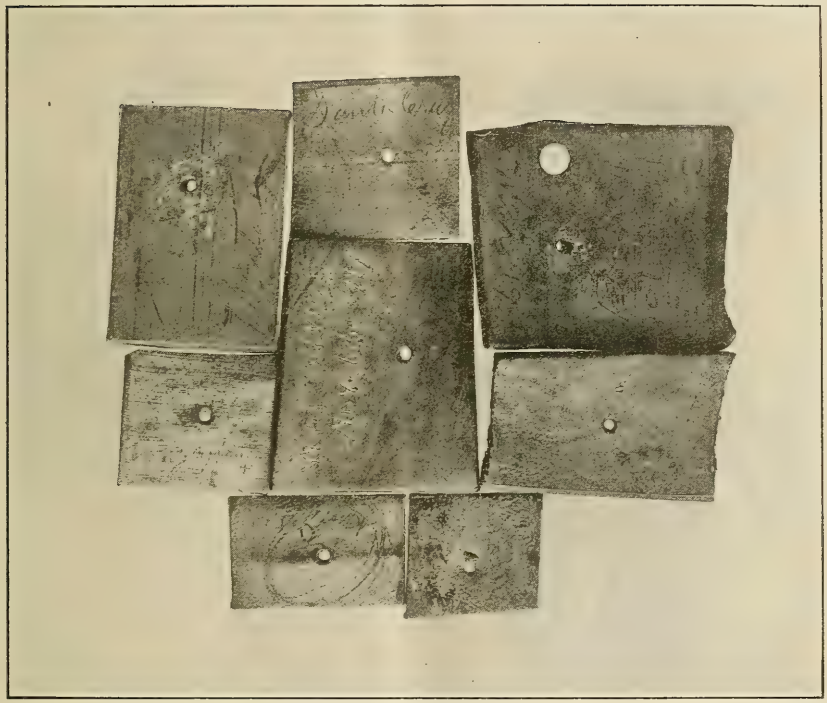

FIG. 3.—Holes bored in the lead sheathing of aerial cables by the California lead-cable borer (*Scobicia declivis*) at various localities in California. Natural size.

OCCURRENCE AND EXTENT OF INJURY TO CABLES IN THE UNITED STATES.[5]

The first report of the boring of cable sheath by insects was received from California in the fall of 1903. It is understood that prior to that time about 100 cases of injury had been experienced over the period of five or six years. The borings occurred adjacent to metal cable hangers, and at first it was thought that the use of mar-

[4] In getting the exact location of and repairing "bug" trouble the linemen travel along the cable on a pulley or sliding seat hung on a messenger cable. Of course the wire trouble or leak is approximately located from the office by means of the "Wheatstone bridge." Injury is remedied by "wiping" a knob of lead on a patch or cutting away the lead and putting on a new joint or "sleeve." Dry holes are merely soldered; that is, where the moisture has not soaked through. (Pl. X, Fig. 1.)

[5] By R. F. Hosford, Engineer, American Telephone & Telegraph Co., New York, N. Y.

line hangers would eliminate injury, but soon reports from other parts of the country demonstrated that this was not so.

In August, 1904, similar damage was reported from Corsicana and Fort Worth, Tex. In the next year boring of cables in the South Atlantic and Gulf States was reported.[6] Damage to cables at Watsonville, Calif., was reported in 1906.

For a number of years following no reports of insect damage were received, probably because the magnitude of the injury was not

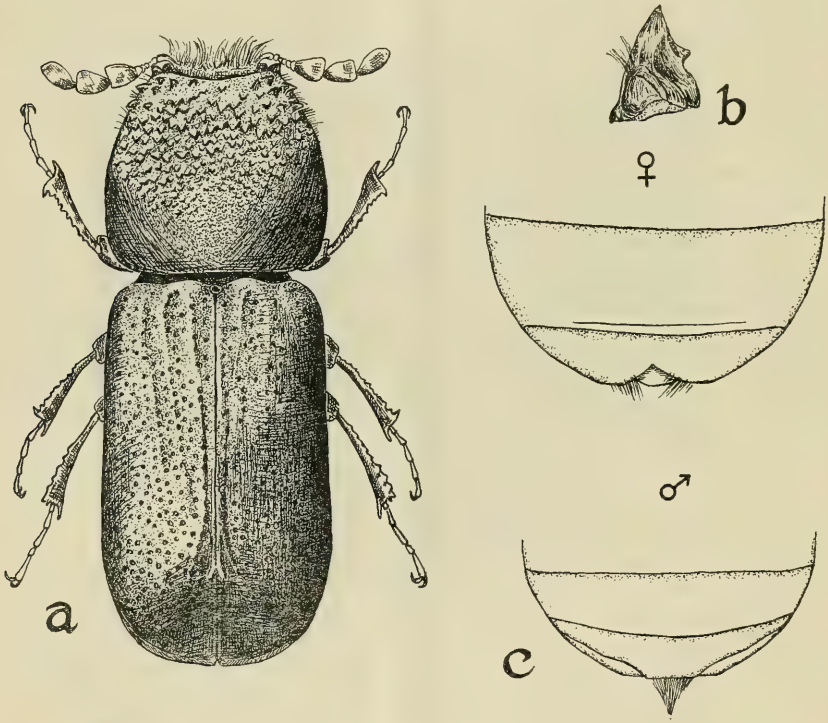

FIG. 4.—The California lead-cable borer (*Scobicia declivis*): *a*, Adult beetle; *b*, left mandible of adult beetle; *c*, sexual differences in adult beetles. *a*, Enlarged 13½ times; *b*, enlarged 26 times; *c*, greatly enlarged.

large from a maintenance standpoint and the cause of the injury had been discovered and made known to the plant forces. It appears from data recently collected that trouble was experienced in Brownsville, Tex., in 1912, and in Los Angeles, Calif., in 1913. The insect damage was not, however, large in comparison with other causes of cable trouble. In the year ending March 31, 1916, insect injury was reported as the cause of about one-fifth of all aerial cable trouble

[6] During the same period scattered cases of the destruction of fuses by insects were reported from several States. In these cases several of the beetles causing the damage were secured and identified as *Dermestes lardarius* L.

in southern California. In 1918 insect injury was reported at Galveston and Houston, Tex., six years after the Brownsville case.

By far the greater number of cases of insect injury to the lead sheathing of aerial cables have occurred in California, where the

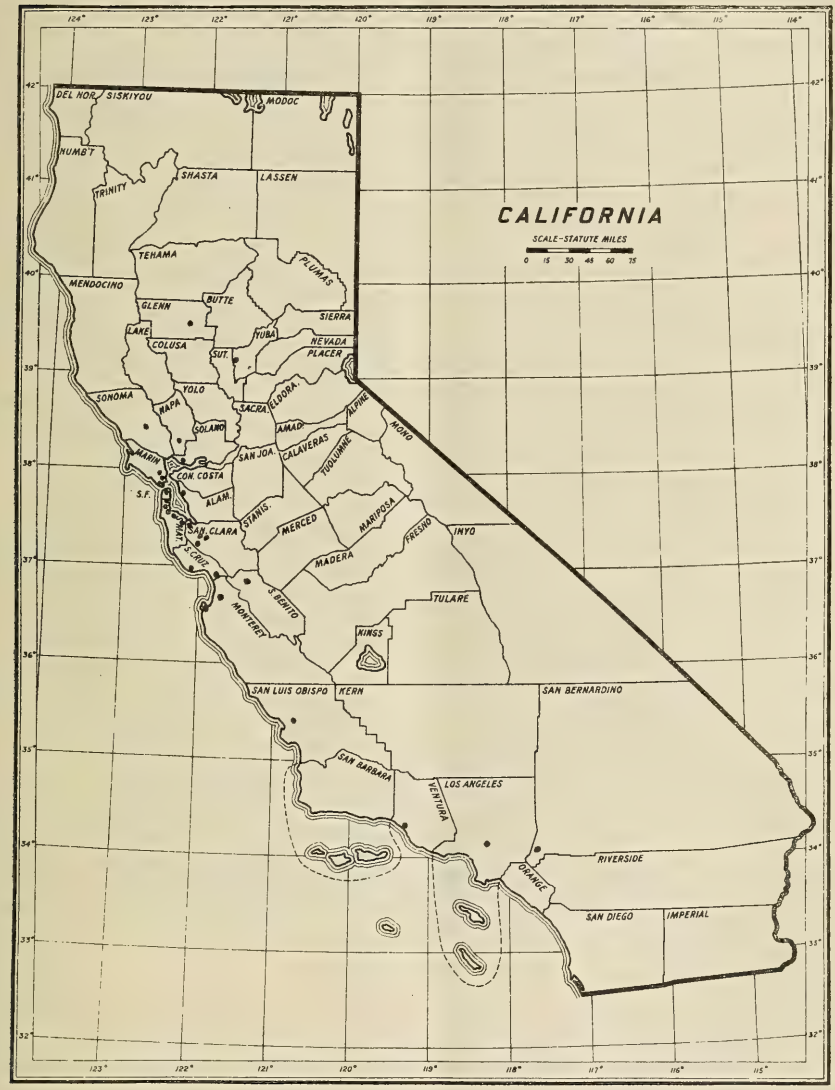

FIG. 5.—Map showing distribution of trouble caused by the California lead-cable borer.

insect responsible for the trouble is the bostrichid beetle *Scobicia declivis* Lec., *54*. (*Sinoxylon declive*, *56*, *58*, *59*, *60*, *61*, *62*, *63*, *66*, *67*; *Xylopertha declive*, *57*, *65*, *66*, *68*; Fig. 4.) Southern California has been one of its principal centers of activity.

Statistical records have not been kept until recently. The California experience of recent years can be seen from the map. (Fig. 5.)

Cable trouble due to insect boring seems to approach most closely to regularity of occurrence in California, where the districts affected extend along the coast from San Diego to some distance north of San Francisco, although trouble has been reported at points as far inland as Sacramento and Marysville.

The extent of the beetle injury to the lead cables appears to vary considerably during different years. In 1913 it was particularly bad at Marysville, in 1917 at Monterey and Salinas, and in 1918 at Watsonville. Part of this variation may be due to the fact that tallow has been used on some cables. There have been no cases of attack found at points protected by tallow, but the experience has not been long enough to indicate whether this freedom from attack is accidental and due to the absence of beetle attack for the years during which the tallow has been under trial or is actually due to its turning the insect away.

It should be noted that occasionally many holes are found in the same piece of cable and are necessarily taken care of in clearing the one case of trouble. The number of holes may vary from 1 to a span (section of cable between two poles, the distance averaging 100 feet) to 125 to a span. In 1913, 106 holes occurred in one span at Marysville; in 1917, 44 occurred under 44 consecutive rings in one span and 30 under 30 consecutive rings in the following span at Monterey; and in the same year 125 holes occurred in one span at Salinas. As one hole may put from 50 to 600 or more telephones out of use for from 1 to 10 days, the damage is rather extensive.

Cases of cable trouble are also occasionally reported where insects, in making their way out of a wooden pole, strike cable laterals or risers and cut into the sheath. One such case was reported from Kingston, N. Y., in the fall of 1918 and another from Orlando, Fla., in July, 1919. In the latter case cable trouble occurred from wetting by a shower before the beetle had cut its way out and it was caught and identified as *Eburia distincta* Hald. Such experiences as these demonstrate that many wood-boring insects are able to cut cable sheath. (Fig. 6.)

The following are additional records reported to the Bureau of Entomology:

A case of insect damage (bostrichid) to cable occurred at Savannah, Ga., in 1915; another at Galveston, Tex., in 1920, caused by *Xylobiops* sp., probably *basilare* Say.

Among the cases where the identity of the insect causing the injury is in doubt is a report to Dr. F. H. Chittenden, of the Bureau of Entomology, in November, 1906, of small punctures in the lead covering of cables at Watsonville, Calif. These were thought to have

been caused by the dermestid *Perimegatoma variegatum* Horn; more probably, however, the damage was due to *Scobicia declivis*, which has injured cables at Watsonville.

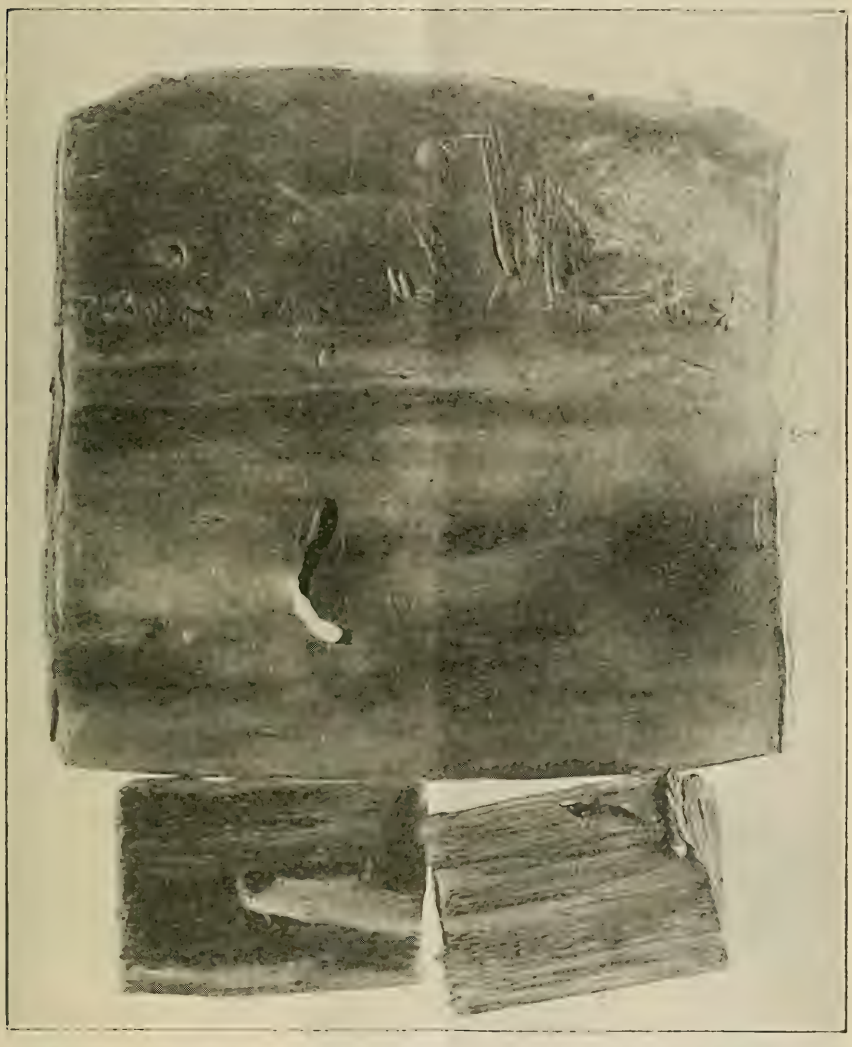

FIG. 6.—Hole accidentally bored through lead sheathing of a cable on a telephone pole by a wood-boring beetle in its efforts to emerge from the wood of the pole. Natural size.

DAMAGE BY THE CALIFORNIA LEAD-CABLE BORER (SCOBICIA DECLIVIS) TO TREES AND FOREST PRODUCTS.

CHARACTER OF DAMAGE.

The usual damage to the wood of trees attacked by the cable beetle is a complete riddling caused by the egg galleries of the beetles and the mines of the larvæ. (Pl. VII, Fig. 3.) When the insects

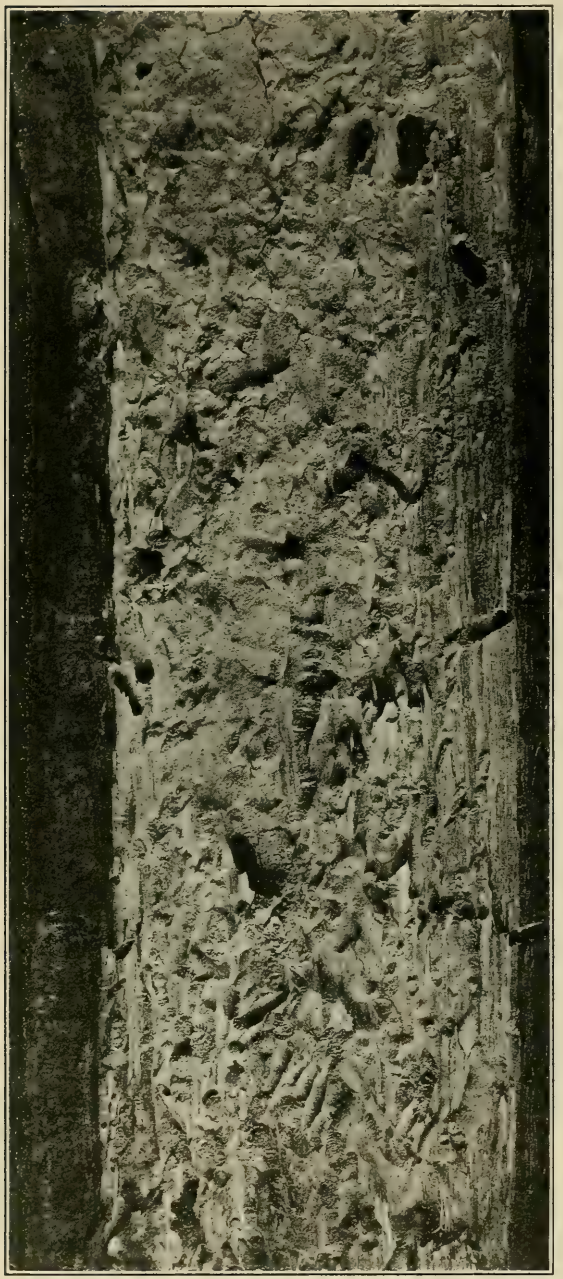

FIG. 7.—Work of the California lead-cable borer in California live oak (*Quercus agrifolia*), Los Gatos, Calif. Note that the wood is "powder-posted." The larger holes were made by a roundheaded borer. Natural size.

are through with a section of wood, nothing remains but the bark and enough solid wood to hold the mines together. All of the rest is reduced to numerous holes (the egg galleries and exit holes) and the winding larval mines closely packed with the meal-like boring dust. (Figs. 7 and 8.)

In special cases the beetles may attack and kill living trees. On September 28, 1919, Mr. Hartman found a cherry tree (*Prunus avium*) in Los Gatos, Calif., with the foliage fading. Close examination showed numerous small holes in the bark at the bases of the branches and buds and in rough spots on the bark of the trunk. Some of these holes contained Scobicia beetles and many of them were the entrances to galleries which encircled the branch or trunk just beneath the surface of the outer wood. No other cause for the dying of the tree could be discovered. No eggs or larvæ were found.

In the laboratory at Los Gatos, numerous beetles which emerged from the wood stored for rearing purposes entered a cedar cigar box containing large vials of alcoholic speci-

mens. Many entered through the partially closed lid of the box but others bored through the sides. After entering the box the beetles burrowed into the cork stoppers of the vials. Some went through the cork to the alcohol, while others bored between the cork and the glass and stopped. (Pl. IX, Fig. 4.)

FIG. 8.—Exit holes of the California lead-cable borer in bark of California live oak, Los Gatos, Calif. Natural size.

Dr. J. J. Rivers (*62*) reported a number of years ago that the beetles damaged wine casks in California by boring across the grain of the wood to the contents. About this same time D. W. Coquillett (*63*) reported that the species mined orange wood and rosebushes. The reference to rose may refer to *Psoa maculata* Lec., nearly related to *S. declivis*.

EXTENT OF DAMAGE.

The work is very common in most of the oak wood used for fuel in central California. This wood is cut during the summer months when the beetles are flying and is particularly likely to be infested. It has been very little trouble to collect all of the infested wood needed for laboratory rearing purposes at the Los Gatos wood yards during the winter months. Practically every fallen tree of any of the oaks in the forests shows extensive work of this species. Dead or dying elms in the parks or along the highways are likely to be similarly infested.

Doctor Rivers (*62*) says that it attacks dry lumber, particularly oak, and especially oaken wine casks, and that it has caused the loss of thousands of dollars to the wine industry. Prof. J. H. Comstock (*60*) also mentions this habit and says that oak, chestnut, pine, whitewood, and eucalyptus casks were used to stop the trouble, but without success.

BIOLOGY OF SCOBICIA DECLIVIS.

DISTRIBUTION.

The insect appears to be widely distributed in California. There are specimens in the Forest Insect collection from Berkeley, Confi-

dence, Hillsborough, Hollister, Lamoine, Los Gatos, Monterey, Nordhoff, Palo Alto, Placerville, Salinas, San José, Santa Cruz, Shingle Springs, Tuolumne, Vade, and Watsonville in California, and Ashland and Hood River, Oreg. Others record it from Cisco, Fort Tejon, Los Angeles, Orange, Pomona, Sacramento, San Nicolas Island, Sonoma, and Sylvania in California. The range in elevation is also great, being from 50 to 5,300 feet.

FOOD PLANTS.

The principal food plants of the cable beetle are the various species of oak. Of these the California live oak (*Quercus agrifolia*) and the black oak (*Q. californica*) appear to be the most important, but heavy infestations have been found in the blue oak (*Q. douglasii*), the white oak (*Q. lobata*), the huckleberry oak (*Q. chrysolepis*), and the tan oak (*Q. densiflora*).

Besides the oaks, the writers have found infestations in the wood of the elm (*Ulmus campestris*), the bigleaf or Oregon maple (*Acer macrophyllum*), the California laurel (*Umbellularia californica*), the sweet cherry (*Prunus avium*), the gum (*Eucalyptus* sp.), and the wattle (*Acacia* sp.). In addition to these, Coquillett (*63*) records the orange and rose as food plants.

ASSOCIATED INSECTS.

The borers commonly associated with the cable beetle in the oaks are the three roundheads, *Xylotrechus nauticus* Mann., *Neoclytus conjunctus* Lec., and *Phymatodes nitidus* Lec., and the powder-post beetle *Lyctus planicollis* Lec. The larval work of the cable beetle usually can be distinguished from the work of the other species because the mines are smaller, circular, and finer than those of the roundheads and larger and coarser than those of Lyctus. (Pl. VII, Fig. 4.) Lyctus also works only in the sapwood. Sometimes the larger powder-post beetles, *Polycaon stoutii* Lec. and *P. confertus* Lec., occur with the cable beetle. The only associate found in the elm is the roundhead *Xylotrechus nauticus*. In the California laurel the common species is the anobiid *Ptilinus ramicornis* Casey, and the cable beetle occurs only in small numbers. The work of the anobiid can be distinguished by the smaller size of the larval mines. The buprestid *Chrysobothris femorata* Oliv. has been reared from infested live-oak wood.

PREDATORY AND PARASITIC ENEMIES.

The predatory and parasitic enemies of the cable beetle do not appear to be very common. One clerid, *Monophylla californica* Fall, is predatory, and one histerid, *Teretrius* sp., may be. The clerid larvæ are found in the mines of Scobicia and of the associated *Lyctus planicollis*. The adult clerids emerge and fly during July and August.

The histerid larvæ appear to be more common in the mines of the Lyctus. The predator *Trogosita virescens* Fab. was reared from infested wood. No Hymenoptera or Diptera were observed in any of the rearings that could be determined as actual parasites of or predators on Scobicia.

LIFE CYCLE.

According to the observations made at the Los Gatos laboratory, the life cycle of the cable beetle is as follows: The mother beetle excavates an egg gallery or burrow in the solid wood and lays her eggs in the pores of the wood from this. (Figs. 10, 14.) The eggs hatch in about 21 days. The larvæ mine in the wood (Pl. III, Figs.

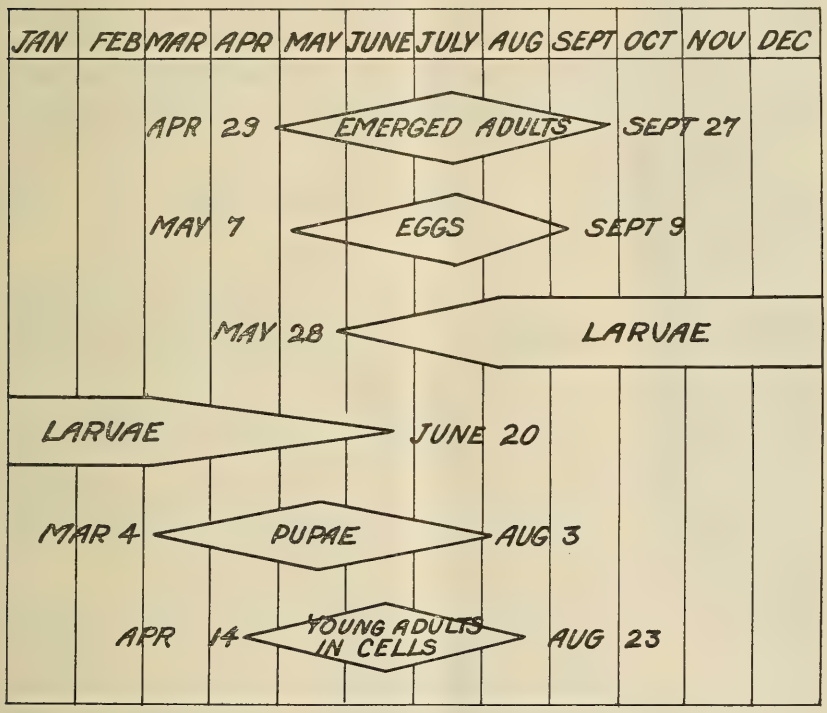

FIG. 9.—Diagram illustrating seasonal history of the California lead-cable borer.

4 and 5) for about nine months, molting about six times. They then become quiet and remain as prepupæ for about six days, whereupon they pupate. The pupa stage lasts for about 14 days and then the transformation to the young beetles occurs. The beetles remain in the wood about 30 days, hardening and maturing. (Pl. III, Fig. 2.) They then eat their way through the outer wood and bark, emerge, and, if females, start new galleries in the same or another section of wood. (Pl. III, Fig. 1.) About the time the galleries are started,

mating occurs (Pl. III, Fig. 3) and the mothers lay their eggs in the wood to start a new generation.

SEASONAL HISTORY.

The lead-cable beetle has only one generation a year. Eggs have been found from May 7 to September 9, larvæ from May 28 one year to June 20 the next year, pupæ from March 4 to August 3, and adults from April 14 to September 27. The beetles are most common in July and August, the maximum emergence being from July 20 to 30. The pupæ are most abundant from May 1 to June 15.

A few pupæ and young beetles were found in their pupal cells in elm in November. Whether these were retarded individuals of the past season's generation or greatly accelerated ones of the coming generation could not be determined.

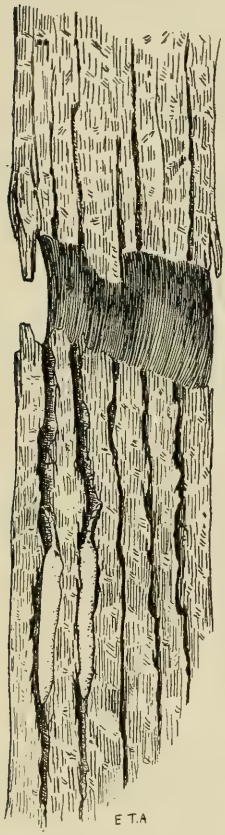

FIG. 10.—The California lead-cable borer: Two eggs in pores of wood near exit hole of adult beetle. Greatly enlarged.

DESCRIPTION AND HABITS.

THE EGG.[7]

Considerable time was spent and patience was necessary in locating and taking notes on the first egg. (Fig. 10.) After the position was found, numerous eggs were ruined in an effort to get them under the binocular, but after a number of attempts it was successfully accomplished. The eggs are very soft, the slightest touch puncturing them, while they quickly shrivel and dry when exposed.

Description.—Egg elongate, about 15 times longer than broad; average length, including stem, 2.1 millimeters; average width, 0.14 millimeter. The end leaving the ovipositor first is rather bluntly pointed, while the end leaving the ovipositor last (or gallery end) has a slender stem attached to it about 0.25 millimeter in length. The egg is somewhat the shape of that of *Lyctus planicollis* Lec., described and figured by T. E. Snyder,[8] yet does not bear any longitudinal striæ. The color when first deposited is pale white, gradually changing to a dull white or cream, the surface being rather dull with a slight granular appearance. The larva occupies about two-fifths of the egg proper when developed, its mandibles showing through the transparent eggshell four to seven days before hatching. The gallery end of egg and stem attachment

[7] The peculiar egg of this beetle was first found by R. D. Hartman.
[8] Jour. Agr. Res., v. 6, no. 7, p. 274–275, pl. 28, 1916.

shrivel considerably before hatching, which takes place on an average 21 days after oviposition.

The Larva.[9]

First stage[10] (Pls. I and II).—In hatching the young larva cuts or tears a hole in the caudal end of the egg with its caudal spine or saw and backs out into the pore of the wood. It then turns around and if the pore at that point is the proper size for it to obtain a leverage it starts mining. If not, it follows down the pore until it does obtain a suitable leverage. During this stage the larva is not curled as in the later stages. After mining a short distance, from 2 to 5 millimeters, it stops and molts to the second stage. The caudal spine is then lost and the curled position assumed.

Later stages.—The mining proceeds parallel with the grain of the wood, the borings being packed into the mine behind the larva. Every so often the mining stops and molting to the next stage occurs. Apparently six molts in all take place before the larva becomes full grown. (Fig. 11.) During the last stages the larva mines deeper into the wood, returning toward the surface just before pupation. It does not mine close to the surface before pupation, however, as do many of the wood-boring roundheads and flatheads, the adults of which are not so able to bite their way through the solid wood.

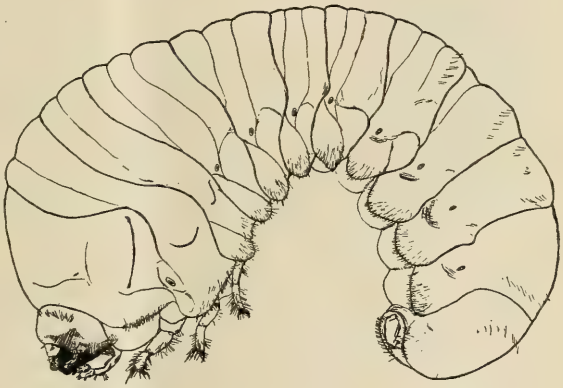

Fig. 11.—The California lead-cable borer: Mature larva. Enlarged 8 times.

In mining the larva assumes the usual curled position and braces itself ventrally with its legs, especially with the spurs on the prothoracic pair and with the anal tergite, and dorsally with the thoracic tergites. The head is on a flexible neck and able to move in any direction. The mandibles, by opening and closing laterally, cut the wood into small particles. Some of these are taken into the digestive system, but most are passed down to the legs, which deliver them into the scoop-shaped abdominal sternites. The excrement is

[9] For detailed description of the larva, by Dr. Adam G. Böving, of the Bureau of Entomology, see Appendix, page 49.

[10] R. D. Hartman discovered the first-stage larva and the fact that Scobicia has different types of larvæ.

also passed into this scoop, the short length of mine between the larva and the packed borings being left open. The mining continues, the larva rolling from side to side, until the abdominal scoop is full of borings. The larva then turns either dorsally or ventrally toward the packed end of the mine and drags the load of borings to it. By thrusting its anal segments forward a number of times it throws the load of borings up to the legs, which pass it on to the mandibles, and these knead it into the mass of borings already firmly packed into the mine.

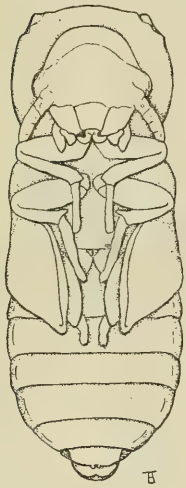

FIG. 12.—The California lead-cable borer: Pupa. Enlarged 8 times.

If a larva is taken from its mine it is unable to travel in any direction it desires. It can wriggle around and roll over and over, but that is about all.

Molts.—A study of the larval mines and cast skins indicates that the larva molts six times before it pupates. The first molt takes place after the larva has mined a distance of from 2 to 5 millimeters from the eggshell, the second from 8 to 15 millimeters, the third from 21 to 33 millimeters, the fourth from 57 to 69 millimeters, the fifth from 130 to 142 millimeters, the sixth from 250 to 290 millimeters, and pupation at about 500 to 580 millimeters.

Prepupal larva.—When the larva becomes full grown it straightens out, becomes shorter, broader, and sluggish, and enters a quiescent stage. No distinct pupal cell is made. The prepupal larval skin gradually turns transparent, showing the pupa within. In about six days the skin breaks at the back of the head and slowly sheds down the head, thorax, and abdomen to the caudal end, where it adheres to the caudal segments of the pupa.

THE PUPA.

The pupa is milk white at first. (Fig. 12.) In from two to four days the eyes and mandibles start to color light brown. The tubercles on the prothorax also are faintly indicated. In from four to seven days the eyes and mandibles have turned dark brown, the prothoracic rugosities a light brown, and the mouthparts, antennæ, prothorax, and legs show some color. In from 10 to 15 days the tubercles have attained the normal black of maturity, the mouthparts, antennæ, and legs have become light amber, and the tibial teeth and spurs dark brown; the prothorax has changed to brown, the abdominal sternites to a light brown, and the abdominal tergites

have started to color. The wing pads now commence to swell and on about the fifteenth day from pupation the struggles of the insect split the pupal skin, the wings and elytra spread over the dorsum of the abdomen, and the transformation to the adult has taken place.

The Immature Adult.

At first the elytra of the young beetle are dull white and rather soft and the small punctures very distinct. The elytra slowly color to light brown, dark brown, and finally black. The abdominal segments also blacken, and in about one month or six weeks the beetle appears full grown. It slowly bites its way to the surface of the infested section and some warm day emerges as a fully matured beetle. (Fig. 4.)

The Mature Adult.[11]

General description.—Form cylindrical, head deflexed; size small (average length, 5.85 millimeters; average width, 2.10 millimeters); the prothorax and abdominal sternites about equal in length. Color dark brown to black, mostly black; antennæ, mouthparts (except mandibles), femora, and tarsi light amber; tibiæ, posterior lateral area of prothorax, and tumid area on the anterior lateral portion of elytra dark amber.

Emerging.—As soon as the adult becomes mature it slowly bites its way to the surface and, selecting a warm day, emerges from the section of wood. The emergence hole can be distinguished by its sharp, square edge and by the fact that usually it is in the open and not hidden in a crevice or similar place. If the weather conditions are not suitable, the beetle will often turn around and go back into the emergence hole for a time before it finally leaves the section.

Flying.—Both sexes are strong fliers and are on the wing a good deal if the weather is warm.

Feeding.—After emergence the males appear to get under a bark scale or similar place and feed while they wait for the females to start their entrance galleries into the new wood. The females do not appear to feed until they have the entrance gallery well started and are into the wood. None were observed to feed on the bark. The male often comes to the gallery and feeds on the borings thrown out by the female.

Boring.—Apparently most of the boring is done by the female. The male may make a short food gallery or impression, but the egg gallery is made by the female. Soon after emergence she seeks a suitable place in which to deposit her eggs. Finding such a place at a knot, scar, bark scale, or crevice in or under the bark or in the wood.

[11] For a detailed description of the mature beetle, see Appendix, p. 54.

between two sections of wood, or where a section of wood rests against something else, in fact any place where the proper leverage can be obtained, she starts boring.

Gnawing, and circling as she gnaws, she soon has in the bark or wood a circular impression with a smooth rounding edge and slightly larger than herself. During this time her claws grasp the bark or wood and her abdomen is parallel with the surface. As soon as the hole is deep enough she gets the prothorax with its rasplike rugosites against one side and with the front pair of legs grasps the other side. The legs of the middle pair brace and push with the tibial spurs, while those of the rear pair extend backward close to the abdomen, which gradually becomes elevated as the boring progresses. Continually gnawing and revolving back and forth, sometimes making a complete circle, she eventually buries herself in the wood perpendicular to the surface. This takes about 24 hours.

Apparently the boring goes on continuously, faster during the warmer part of the day and slower during the cooler night time. The borings are kicked out by the legs. As the gallery deepens the insect has to back up, kicking out the borings as she comes. The male often assists the female by pushing against her declivity with his mandibles, thus adding weight and stability to the hold. He also assists in throwing out borings when the gallery gets deeper.

When the gallery has reached a depth of about 8 millimeters, which is slightly more than the length of the female, it turns rather abruptly, curves backward toward the surface, and then runs parallel to it across the grain of the wood. (Pl. III, Fig. 1.) The length varies from a few millimeters to 125 millimeters, or about 5 inches. The average length is about 63 millimeters, or 2½ inches.

Mating.—Mating usually takes place about the time the female has bored her length into the wood. Sometimes in the laboratory pairs were found mating on windows, etc., but most of the observations indicate that this is abnormal. Usually the mating is started by the male clawing at the declivity of the female with his front feet. Sometimes, however, he backs up to her and uses his back feet. Upon being clawed, the female protrudes her anal segments with the sexual organ, whereupon the male places the tip of his abdomen to hers and they mate. (Pl. III, Fig. 3.) Copulation lasts from 10 to 70 seconds. Our records show that one copulation is sufficient. One female laid at least 140 fertile eggs after being separated from the male. (See diagram, Fig. 13.)

Egg laying.—As the egg laying occurs in the wood it was not observed, but the observations made on the egg galleries and the eggs shortly after they were laid indicate how it was done. Any time after the female has reached the solid wood she places the ovipositor

in a suitable pore at the side of the gallery and deposits an egg from 1 to $2\frac{1}{2}$ millimeters into the pore from the gallery. (Fig. 14.) Only a single egg is deposited in each pore. Apparently the pores are selected with considerable care, for oftentimes the gallery runs for

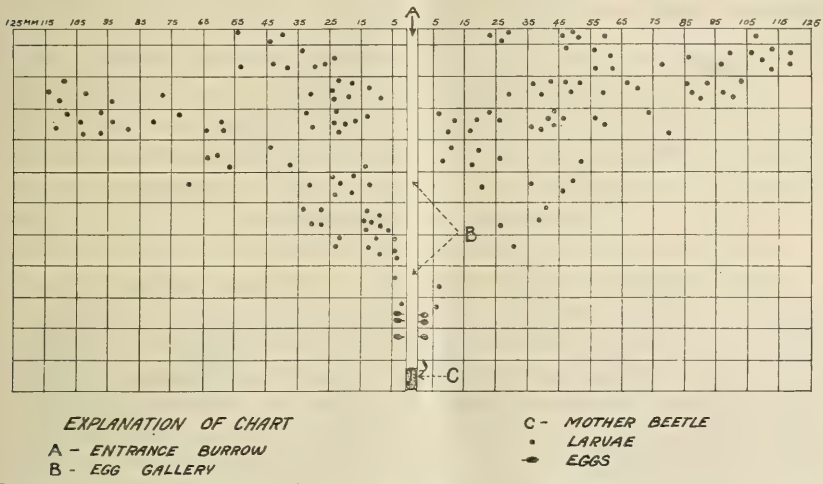

FIG. 13.—Diagram of section of oak wood with which one pair of adults of the California lead-cable borer were placed, showing resulting infestation. May 19, 1920, 5 p. m. Pair of adults placed with section of oak. May 20, 1920, 10 a. m. Female started entrance gallery. Male assists. May 20, 1920, 4.30 p. m. Male taken short distance away several times. Always returned. Pair mate. May 21, 1920, 12 m. Female about twice its length in wood. Male removed. May 22 to June 21, 1920. Female still boring. Section of wood cut up and examined thoroughly. Female at terminus of gallery, weak. Gallery 115 millimeters long. Larvæ and eggs found as indicated. (Distances in millimeters.)

some distance between places where eggs are laid. The indications also are that in going back and forth to throw out the borings from the entrance the female may stop at any point along the way and lay an egg in the nearest suitable pore; at least the variation in

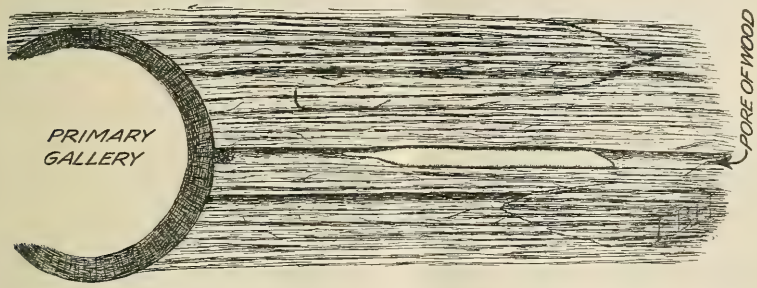

FIG. 14.—Egg of California lead-cable borer in pore of wood. Enlarged about 21 times.

the sizes of the larvæ and the length of their mines indicate this. (See diagram, Fig. 13.) She must also back down and lay, because eggs are found so close to the terminus of the gallery that any other method of oviposition seems impossible.

Healthy wood cut, felled, or broken by the wind and down from two weeks to six months seems to be preferred by the beetle when she excavates the egg gallery. If there is none of this accessible, she will enter logs or stumps from which she has emerged or attack other dead or dying material. She does not like to enter wood killed by fungi or other slow-killing timber diseases.

Length of life.—The females live longer than the males. In the cages with sections of wood the males lived from 10 to 18 days and the females from 30 to 44 days. In the cages, on the cables where there was no wood, both sexes died in from 5 to 7 days.

CONTROL EXPERIMENTS.[12]

TESTS AT FALLS CHURCH, VA., 1918 AND 1919.

In 1918 a large quantity of California oak (*Quercus agrifolia*) (500 pounds) infested with *Scolicia declivis* was shipped by Mr. Burke from Los Gatos, Calif., to the forest insect field station of the Bureau of Entomology at Falls Church, Va. This was placed in a large, specially constructed cage. In June adults began to emerge and some were caged in glass cylinders with covers of test-sheet lead. In some cases the smooth lead was marked—criss-crossed with a nail so that the beetles would not slip; in other jars small strips of copper were nailed to the lead so that an arch was formed to enable the beetles to get a footing on the smooth lead and brace themselves to bore. Adults so caged, when they lost their footing, often spun around the smooth lead on their heads (partly flying) in attempting to regain a foothold. They did not bore through the test lead sheathing under these conditions, and all the efforts to assist the beetles failed.

Other adults were left to fly freely in the large cage to attack the suspended cables of different alloys hung on various types of rings, wire and tape. (Fig. 15.) Several pairs of these adults infested the corks from 100-millimeter vials, constructing their galleries in the corks.[13] The beetles entered the heavy beams (Southern yellow pine) supporting the cage and the old California laurel limbs. They did not attack the suspended cables.

Sheet lead of different alloy composition was tightly wrapped around infested sections of logs, the sides being overlapped and nailed into close contact with the wood. (Pl. VII, Fig. 1.) The ends also were covered. Many adult beetles bored through double thickness of No. 3 alloy lead (99 per cent lead, 1 per cent antimony); No. 2 (95 per cent lead, 4.5 per cent antimony, 0.5 per cent tin), and

[12] These control experiments were made in active cooperation with the American Telephone & Telegraph Co. and associated companies, who supplied the metals, alloys, etc., and installed the test cables in Virginia and California.

[13] There are records of the adults entering a loaf of bread in California and a Douglas fir window sill in Oregon.

No. 1 (commercially pure lead) were also penetrated. The lead sheathing is over one-sixteenth inch in thickness.

RESULTS OF EXPERIMENTS AT FALLS CHURCH, VA., 1918 AND 1919.

It is believed that the results obtained at Falls Church, Va., *were not conclusive* and that climatic conditions may be an important factor influencing attack by the beetles. The No. 4 lead, with a higher per cent of tin in the alloy (97 per cent lead + 3 per cent tin), was not attacked. The sheets of lead No. 5 (commercially pure), with emery embedded, were not large enough to wrap about the logs. Antimony is apparently of no value in resisting the attack of the beetles.

It was decided that this test should be continued in California and that no further infested wood should be shipped to the East. Of

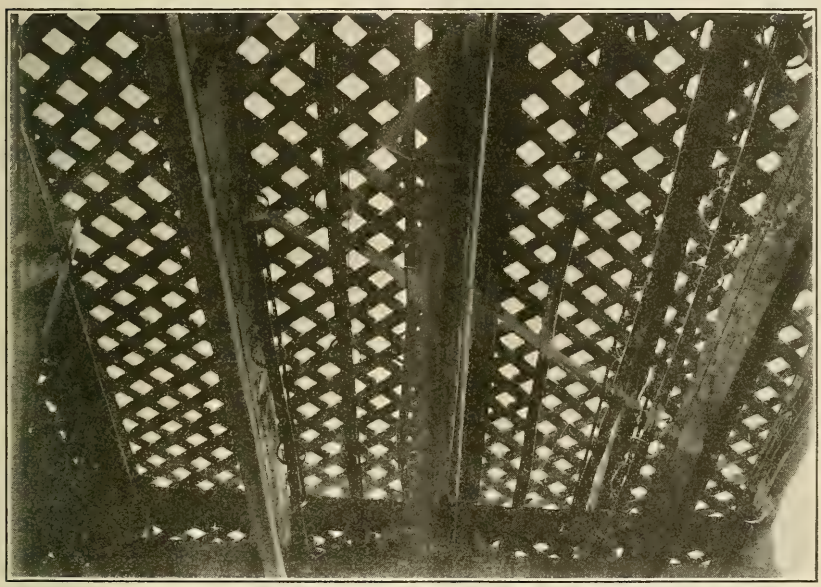

FIG. 15.—Interior of experimental cage at Falls Church, Va., showing lead-sheathed cables of different alloy composition suspended on different types of rings from beams of roof.

course, this is not an absolutely fair test, since it is well known that emerging insects will, if necessary, penetrate materials which they would not ordinarily attack.

Lead embedded with emery has a disadvantage in that it will rust, will "run," and would discolor whatever it fell on beneath the aerial cable.

TESTS AT LOS GATOS, CALIF., 1918–1920.

EMERGENCE EXPERIMENTS.

To determine just what the beetle is able to do and, if possible, to find a repellent or nonpenetrable substance for a cable sheath, a

number of sections of infested wood were treated with various repellents and poisons and covered with various alloys, metals, and other promising materials in such a manner that these would have to be penetrated before emergence could take place. Usually the sections were dipped in the liquids, painted with the heavier fluids, and rolled up into or covered with the metals. In all cases parts of the sections were left untreated or uncovered to serve as checks.

The following materials were used during the various tests from year to year (1918 to 1920): Beef tallow; a commercial brand of refined paraffin; a mixture of the tallow and the refined paraffin; arsenate of lead; a water solution of sodium silicate similar to "water glass"; creosote; No. 38 varnish; spar varnish; tire tape (the common friction tape used by electrical workers); tarred building paper; commercially pure lead sheathing (referred to as "No. 1 lead"); lead-antimony-tin sheathing, or "No. 2 lead" (95 per cent lead, 4.5 per cent antimony, 0.5 per cent tin); lead-antimony, containing 94 per cent lead and 6 per cent antimony) ("No. 2a lead"); lead-antimony, containing 99 per cent lead and 1 per cent antimony ("No. 3 lead"); lead-tin, containing 97 per cent lead and 3 per cent tin ("No. 4 lead"); commercially pure lead embedded with emery filings; lead carborundum coated; lead copper coated; lead tin coated; zinc 0.01 inch thick; and sheet steel 0.006 inch thick.

After being treated the sections were placed in the open laboratory under conditions of normal temperature and moisture. All of the infesting insects seemed to have transformed naturally and carried on their regular functions in a normal manner.

Attacking Experiments.

As it was realized that the insect probably would put forth every effort to emerge and that to do this it might go through repellents and other substances which it would not otherwise attack, a number of uninfested sections of oak and other woods in the proper condition for attack were treated and exposed to attack. The following materials were used to treat these sections: Arsenate of lead paste, black paint, P. & B. paint (a protective paint used by the telephone company workers), pine tar, black iron enamel, white porcelain enamel, creosote, carbolineum (a high grade of coal-tar creosote), nicotine sulphate containing 40 per cent of nicotine, a solution of sodium silicate, a refined paraffin, two grades of a commercial chlorinated naphthalene compound, beef tallow, and varnish.

In order to get a good check on the action of the substances used, untreated sections of wood were kept under the same conditions as the treated sections. Some of the sections were left exposed in the open laboratory where numerous beetles were flying every day during

the season, and others were confined in lamp-chimney cages with freshly emerged beetles.

Cable Experiments.

Besides the experiments with the insects and the wood, a number of experiments were conducted with the insects and the regular telephone cables (Pl. X, Figs. 1–4) to see if any facts could be discovered that would throw light on the reason for the attacks and the methods of preventing them.

Caged cable.—Two large screened cages were built out of doors and a number of cables were suspended in these in as normal a manner as possible. Different types of suspension rings were used and some cables were charged with a 60-cycle lighting current of electricity, while others were left uncharged. Numerous freshly-emerged beetles were placed in the cages, some unconfined and some confined in smaller cages built around a short length of cable and one or two suspension rings. (Pl. X, Figs. 2 and 4.) Some sections of the cable were treated with substances to make it more or less attractive or to trap the insects. These substances were oak-bark tea, tallow, refined paraffin, P. & B. paint, and pine tar.

Service cable.—To be sure that the actual conditions met with in the commercial cables were present in the experiments, several small cages were placed around the service cables of the Los Gatos Telephone Co. (Pl. X, Fig. 1.) These were kept supplied with beetles and the results noted. Some of the cages inclosed suspension rings and others were attached between the rings close enough to the lead to allow the beetles leverage for boring at any point along the cable.

Several tests were made on the commercial cables to see if any magnetic fields existed about them, but no evidence was found that any existed. Several times beetles were placed in a magnetic field created by an ordinary magnet, but so far as could be determined this had no effect on them.

RESULTS OF EXPERIMENTS AT LOS GATOS, CALIF., 1918–1920.

Emergence Experiments.

As the emergence experiments were numerous, the results can best be given in a series of tables (Tables 1–4) and photographs (Pls. IV–IX). None of the metals, repellents, or poisons used appeared effective against normal emergence except the zinc (Table 2), (Pl. VI, Fig. 4), steel (Table 2) (Pl. IV, Figs. 1–3), and possibly friction tape (Table 2). The beef tallow when softened by the sun stopped the emergence (Table 4) (Pl. IX, Fig. 1). As at Falls Church, Va., beetles entered 30-millimeter corks used as stoppers to vials containing alcohol. (Pl. IX, Fig. 4.)

TABLE 1.—*Emergence of beetles of the lead-cable borer through metals and other material applied in layers to infested sections of wood; Los Gatos, Calif., 1918–1920.*

Experiment No.	Number of layers used.	Order in which leads and other metals were applied, starting next to the wood (numbers refer to kinds of lead, p. 22).	Number of beetles emerging from wood under metal.	Number of beetles escaping between metal and wood.	Number of beetles stopped by first layer of metal.	Other adults penetrated the various layers as follows.								Remarks.
						First.	Second.	Third.	Fourth.	Fifth.	Sixth.	Seventh	Eighth.	
55c	8	Carborundum[1] up	9	1	0	8	8	5	1	1	1	0	0	Only one beetle penetrated more than 3 layers. It penetrated 6.
21a	8	Emery-lead down, 4, 3, 2, 1, 2a, sheet steel, zinc.	16	1	8	7	7	4	2	1	1	(2)	(3)	Last one was stopped by sheet steel.
25a	7	3, 2, 2a, steel, 1, zinc, 2a	30	13	7	10	10	10	(2)	5	[3] 5	5	.....	Smaller strips of steel and zinc were used. The last 5 beetles mined on either side of these. Five were stopped by steel.
25b[4]	6	2, 4, zinc, 1, steel, 2a	30	14	4	12	10	[3] 1	0	0	0	.....	.....	In this case no beetles mined to the side of the zinc or the steel as in No. 25a.
25c	6	4, 3, steel, 2a, zinc, 1	22	8	1	13	11	(2)	0	0	0	.....	.....	In this case no beetles mined to the side of the zinc or the steel as in No. 25a.
26a	6	Carborundum up, copper up, 2a, 2, steel, 1.	84	29	14	41	37	35	29	(2)	20	.....	.....	9 were stopped by strip of steel; 20 mined to the side and escaped.
26b[5]	6	Carborundum down, copper down, 2a, 2, steel, zinc, 1.	64	1	13	50	42	37	31	(3)	11	.....	.....	20 were stopped by zinc; 11 mined to the side and escaped.
26c	6	Copper up, carborundum up, 2a, 2, steel, 1.	22	13	0	9	7	7	6	(2)	2	.....	.....	4 were stopped by steel; 2 mined to the side and escaped.
26d	6	Copper down, carborundum down, 2a, 2, zinc, 1.	13	4	2	7	7	5	4	(3)	4	.....	.....	No adults mined under strip of zinc.
27	6	2 sheets carborundum together, 3, 4, 1, 2a.	35	15	0	20	17	14	13	10	9	.....	.....	3 stopped in the second layer of carborundum down.
28	6	2 sheets copper together, 3, 4, 1, 2a.	35	18	5	12	10	10	7	6	4	.....	.....	2 stopped in the second layer of copper down.
2A[6]	4	2, 3, emery down, 4	23	5	6	12	12	3	2	.....	.....	.....	.....	9 were stopped by emery down.
2B[6]	4	3, 4, 2, emery up	18	11	0	7	7	7	5	.....	.....	.....	.....	2 stopped by the last layer before they reached emery.
1W	4	Emery up, 3, 4, 2	18	3	11	4	4	4	4	.....	.....	.....	.....	4 that penetrated the first layer also went through the last.
26E	7	Layers of building paper.	21	0	0	21	20	16	8	4	4	4	.....	

[1] "Up" means that the lead was between the infested wood and the carborundum; the word "down," used elsewhere, denotes that the material described is next to the infested wood.

[2] Steel. [3] Zinc. [4] See Pl. V, Fig. 3. [5] See Pl. V, Figs. 1 and 2. [6] See Pl. V, Fig. 4.

NOTE.—Besides these a large number of single-layer experiments were conducted. As the same lead was used in the above it would be useless to tabulate them. No differences could be detected in the ability of the sexes to penetrate the various alloys and other substances used in the experiments.

TABLE 2.—*Emergence of beetles of the lead-cable borer through metals and other materials wrapped around infested sections of wood; Los Gatos, Calif., 1918–1920.*

Experiment No.	Kind of metal used.	Number of layers or thicknesses used.	Total number of beetles emerged from the wood.	Number of beetles escaping between wood and metal.	Number of beetles stopped by first layer.	Other adults penetrated the various thicknesses, as follows: First.	Second.	Third.	Fourth.	Fifth.	Sixth.	Seventh.	Eighth.	Ninth.	Fourteenth.	Nineteenth.	Twenty-fourth.	Remarks.
55*b*	No. 1 lead	10 to 11	45	4	21	20	14	11	10	9	9	3	....	....	....	....	....	No adult penetrated all of the layers.
19	No. 2a lead	4 to 5	29	3	6	20	17	14	12	2	....	....	....	....	....	....	....	Eight emerged and escaped through the fourth, leaving two in fifth.
20*a*	Do	4 to 5	18	0	4	14	13	9	8	4	....	....	....	....	....	....	....	Three emerged and escaped through the fourth, leaving one in fifth.
55*a* [1]	Do	26 to 27	48	4	7	37	34	32	28	27	26	24	21	18	13	8	2	This was greatest penetration, about 1 inch.
4 [2]	No. 3 lead	1 to 2	27	5	13	9	3	....	....	....	....	....	....	....	....	....	....	Six emerged through first and escaped. Layers unevenly rolled.
3	No. 4 lead	2 to 3	38	3	12	23	14	2	....	....	....	....	....	....	....	....	....	Twelve emerged through second and escaped.
51	Tinned down	6 to 7	10	4	1	5	3	3	3	2	1	....	....	....	....	....	....	Last two emerged at fifth and sixth and escaped.
52 [3]	Do	2 to 4	58	3	31	24	20	2	2	....	....	....	....	....	....	....	....	Eighteen emerged through second and escaped.
60	Do	6 to 9	15	2	10	3	3	3	2	1	1	1	....	....	....	....	....	Three strips were rolled together.
54*c* [4]	Do	3 to 4	14	1	7	6	4	4	2	....	....	....	....	....	....	....	....	Two emerged through third and escaped.
33*a*	Copper down	1 to 3	11	2	7	2	2	2	....	....	....	....	....	....	....	....	....	
54*b* [4]	Do	3 to 4	17	1	4	12	7	4	4	....	....	....	....	....	....	....	....	
33*b*	Copper up	2 to 3	19	6	9	4	3	3	....	....	....	....	....	....	....	....	....	
29*b*	Carborundum down	2 to 3	26	0	10	16	8	3	....	....	....	....	....	....	....	....	....	Four emerged through second and escaped, one stuck in three.
54 [4]	Do	3 to 4	17	0	3	14	6	1	....	....	....	....	....	....	....	....	....	One emerged through third and escaped, leaving none for fourth.
29*a*	Carborundum up	2 to 3	5	4	0	1	1	1	....	....	....	....	....	....	....	....	....	The one that started went through all three.
22*a*	No. 2a lead, steel	3	11	3	0	8	....	[5] 8	....	....	....	....	....	....	....	....	....	No. 2a lead was rolled down or next to section.
22	Do	2 to 3	10	2	0	8	4	[5] 4	....	....	....	....	....	....	....	....	....	Same as No. 22a except that No. 2a lead is wider.
45–49 [6]	Zinc	2 to 3	228	0	225	3	[7] 76	....	....	....	....	....	....	....	....	....	....	No adults emerged through zinc.
39–44	Steel	2 to 3	176	0	[8] 176	....	....	....	....	....	....	....	....	....	....	....	....	
66*a*	Friction tape	1 to 2	10	0	3	7	[9] 4	....	....	....	....	....	....	....	....	....	....	
66*b*	Do	1	3	0	1	[10] 2	....	....	....	....	....	....	....	....	....	....	....	

[1] See Pl. VII, Fig. 1, and Pl. IX, Fig. 3.
[2] See Pl. VI, Fig. 1.
[3] See Pl. VI, Fig. 2.
[4] See Pl. VIII, Fig. 3.
[5] Stopped by steel.
[6] See Pl. VI, Fig. 4.
[7] Made impressions on zinc.
[8] None made any impression on steel.
[9] None emerged.
[10] Both emerged through one layer.

TABLE 3.—*Emergence of beetles of the lead-cable borer through metals partially treated with repellents and poisons and wrapped around infested sections of wood; Los Gatos, Calif., 1918–1920.*

Experiment No.	Repellent used.	Where applied.	Kind of area.	Total number of beetles emerged from wood.	Number of beetles escaping between wood and metal.	Number of beetles stopped by first layer.	Other beetles penetrated the various layers, as follows:				
							First.	Second.	Third.	Fourth.	Fifth.
64	Three coats spar varnish on No. 3 lead	Half of underside, then rolled three to four times.	Untreated area	12	0	8	4	1	1	1	.....
			Treated area	16	3	7	6	3	2	2	.....
50	Three coats spar on section and three coats spar on No. 3 lead.	Half of underside, then rolled four to five times.	Untreated area	1	0	1	0	0	0	0	0
			Treated area	7	2	3	2	2	1	1	1
56 [1]	Three coats spar on section and five coats spar on No. 3 lead.	do	Untreated area	9	2	2	5	3	3	3	3
			Treated area	10	1	2	7	7	6	4	3
18	One coat of spar on section and one coat of spar on No. 3 lead.	Half of underside, then rolled three to four times.	Untreated area	2	1	0	1	0	0	0	.....
			Treated area	3	1	2	3	2	1	1	.....
16	1 coat spar on No. 2 lead	Half of underside, then rolled two to three times.	Untreated area	9	4	3	2	1	1	.....	.....
			Treated area	23	4	9	10	6	4	.....	.....
15	Do	do	Untreated area	8	3	3	2	2	1	.....	.....
			Treated area	14	7	6	1	1	1	.....	.....
62 [2]	Three coats spar on section and three coats spar on No. 4 lead.	Half of underside, then rolled four to five times.	Untreated area	2	3	3	2	1	1	1	.....
			Treated area	4	4	5	4	3	1	1	0
12	One coat No. 38 varnish on No. 4 lead	Half of underside, then rolled two to three times.	Untreated area	3	1	2	0	0	0	.....	.....
			Treated area	12	3	5	4	2	0	.....	.....
11 [3]	Medium coat beef tallow on No. 4 lead	do	Untreated area	23	8	0	15	8	6	.....	.....
			Treated area	37	0	12	25	13	8	.....	.....
9	Heavy coat of paraffin on No. 3 lead	Covered all of underside, then rolled two to three times.	All treated	32	6	15	11	5	3	.....	.....
59	Four coats spar on section	Rolled carborundrum lead down, four to six times.	do	13	0	7	6	3	2	1	0
61	Three coats No. 38 varnish on section	Rolled copper lead down, four to six times.	do	15	0	8	7	2	1	1	0
10	Heavy coat arsenate of lead on section	Portion of section rolled with three layers of No. 4 lead.	Poisoned and rolled with lead.	7	2	5	4	3	2	.....	.....

[1] See Pl. VIII, Fig. 2. [2] See Pl. VII, Fig. 2. [3] See Pl. IX, Fig. 2.

TABLE 4.—*Emergence of beetles of the lead-cable borer from infested sections of wood through poisons, repellents, and varnishes; Los Gatos, Calif., 1918–1920.*

Experiment No.	Repellent used.	Where applied.	Number of adults emerged in treated area.	Number of adults emerged in untreated area.	Total number of adults emerged from infested section.
1	5 coats No. 38 varnish	All of infested section	63	.....	63
2	4 coats No. 38 varnish	Four-fifths of infested section	78	13	91
3	3 coats No. 38 varnish	Two-thirds of infested section	48	31	79
4	5 coats spar varnish	All of infested section	102	.....	102
[1] 5	do	Two-thirds of infested section	46	11	57
6	4 coats spar varnish	Four-fifths of infested section	54	20	74
7	3 coats spar varnish	Three-fourths of infested section.	73	18	91
[2] 8	1 heavy coat beef tallow	do	26	8	34
9	1 heavy coat of refined paraffin	do	53	18	71
10	3 coats of water solution of sodium silicate.	do	93	35	128
11	Heavy coat of lead arsenate	One-half of infested section	33	30	63
[1] 12	1 coat white enamel paint	Three-fourths of infested section.	37	18	55

[1] See Pl. VIII, Fig. 1. [2] See Pl. IX, Fig. 1.

NOTE.—So far as could be determined, none of these materials hindered the emergence of the beetles to any extent. The beef tallow when allowed to soften in the sun suffocated the beetles and prevented their emergence.

ATTACKING EXPERIMENTS.

Arsenate of lead.—Sections of oak and elm were covered thoroughly with full-strength arsenate of lead paste and placed in individual lantern globes with beetles. Nineteen out of twenty-five entered the sections and showed no effect from the poison. Normal galleries were excavated and eggs laid which hatched into healthy larvæ.

Black paint and one-third creosote.—Four out of six beetles entered at once.

P. & B. paint.—Numerous entrances made. Beetles were able to walk on surface of paint soon after it was applied.

Pine tar.—Thoroughly attacked. The surface remained "sticky" for a short time, especially in warm weather.

Black iron enamel.—Used both straight and mixed with one-third creosote. The beetles attacked and penetrated without trouble.

White porcelain enamel.—Nine out of twelve beetles soon entered.

Creosote.—When sections were treated with pure creosote and placed in the lantern-chimney cages the fumes killed the beetles. When these same sections were taken from the chimneys and placed in the open laboratory the beetles attacked them and entered the wood.

Carbolineum.—The beetles react to carbolineum about the same as to creosote. Some died in a few days after being placed in the chimneys with freshly dipped sections but a few bored into the sections through the carbolineum coat.

Nicotine sulphate.—The fumes of this tobacco product acted as did the creosote. Beetles placed in chimney cages with sections of wood treated with it soon died. This effect soon wore off, however, and beetles entered the wood through the insecticide after the sections of wood remained in the open air for a time. When one-third nicotine sulphate was added to black iron enamel and white porcelain enamel the fumes were strong and kept the beetles from entering while the sections were in the small cages. As soon as they had aired for a time the beetles entered.

Water solution of sodium silicate.—In 1919 a number of sections were treated with this preparation. In only 1 case out of 45 did a beetle enter a treated section, and in this case it appeared to be because of a faulty application. When the material was tested with water, however, it appeared soluble, and therefore its use for cable protection would be impracticable.

Refined paraffin.—This had no repellent effect upon the beetles while it was cold and hard. Some bored into a cake of it. When the weather was warm it softened enough to kill them when they bored into the wood through it.

Chlorinated naphthalene compounds.—These were received too late for a thorough test. Several sections of wood were treated and placed in the chimney cages and beetles introduced. The insects entered through the thinly coated sections without trouble, but died without entering the thicker coated ones. This may have been due to the fact that it was the last of the season and they were weak.

Beef tallow.—Numerous sections treated with this were placed in the cages with beetles. During the early part of the season when the weather was warm and the tallow soft the beetles were killed as they attacked. Sections, even after the tallow had melted off, were immune as long as the weather was warm. (Pl. IX, Fig. 2.) Sections treated later in the season, when the heat did not soften the tallow after it was applied, were attacked by the beetles, which entered the wood and laid their eggs. (Pl. IX, Fig. 1.)

Beef tallow-refined paraffin.—Sections treated with a mixture of two-thirds tallow and one-third refined paraffin kept out the beetles as long as the mixture was soft enough to kill them.

Varnish.—Three and four coats of spar varnish were applied to a number of recently cut sections of oak. The beetles entered these and laid their eggs.

CABLE EXPERIMENTS.

Caged cable.—Several thousand beetles were placed in cages containing cables suspended in the usual manner by rings from messenger strand. Some of these cables carried the usual current of electricity.

while others did not. In none of the cases observed were any beetles found that had made an attempt to enter the cable. As a matter of fact, they paid no attention whatever to it. Painting it with fresh and old oak-bark tea and other substances seemed to have no effect on them as long as they had the large cages in which to fly. They walked on the P. & B. paint and the pine tar soon after they were applied without getting stuck.

Numerous beetles were then placed in small cages which confined them closely to the cables. These also failed to attack except in one case where the cable had been painted with a tea made from fresh oak bark and kept in a tight jar for some time. Eighteen beetles were placed in this cage and fifteen attempts to penetrate the cable were found. Five of these were one-fourth to one-half penetration and the others less than that.

During this same time numerous beetles entered an oak stick that was placed in the large cage, which indicated that they were in the proper stage of maturity to make the experiment practical.

Service cables.—Five hundred and sixteen beetles were placed in five small cages on the service cables in Los Gatos. One of these cages inclosed rings and marline ties and the screen was not close enough to the cable for the beetles to attack anywhere but at the rings; the other cages were between the rings, and the screen was close enough to the cable so that the beetles could attack from any point. One of these cages was painted with black paint to see if this would give a better foothold, but it proved a failure. One hundred and twenty-nine beetles were placed in the first cage, which allowed for the regular attack to be made at the suspension rings or marline tie. None made any attempt on the cable. Three hundred and seventy-six beetles were placed in the other three cages, where an attack could be made at any point. In all three of these, attacks on the cable were made, 5 in one, 11 in one, and 7 in the third, or a total of 23 attacks. Of these only 1 went completely through the sheath, 6 bored from one-third to one-half through, and the others made only slight impressions in the lead.

NOTE.—To get an idea of the ease of applying various substances to the cables, the following cooling tests were made. In each case the material was heated to a liquid state and then left standing until it hardened again.

Beef tallow	Hardened in 1 hour, 10 minutes.
Refined paraffin	Hardened in 20 minutes.
A chlorinated naphthalene compound, No. 1001	Hardened in 10 minutes.
A chlorinated naphthalene compound, No. 1008	Hardened in 7 minutes.

This indicates that the tallow would be much more easily applied than any of the other compounds that would soften under the heat of the sun.

EXPERIMENTS IN CALIFORNIA DURING THE SEASON OF 1921.

The results obtained from the experiments of 1918 to 1920 suggested the most promising ones for the season of 1921. Two lines of investigation are involved: (1) To determine why the insect attacks the cable, and (2) how to prevent the attack.

The bark of the wood normally attacked by the beetles is dark. To see if color has any influence on the attack, paints of various colors were applied to sections of wood and sections of cable.

As beetles appear to be attracted to ferments in the case of the oak tea, wine casks, and vials of alcoholic specimens, several of these liquids were applied to sections of wood and sections of cable to determine their influence. In the experiments of 1920 the beetles were not attracted to the cables in cages when alternating current of commercial frequency was applied to the conductors, but they did attack the commercial cables in town (Los Gatos) in parallel tests made that year. During 1921 the cooperating telephone company supplied apparatus whereby alternating current of talking frequencies could be applied to the cable conductors with a view to determining whether the higher frequencies of the talking current had any influence in producing the attack on the service cables.

As the results obtained by the use of repellents, poisons, alloys, etc., indicate that the repellents and poisons are useless and that the alloys are very little, if any, better than the regular commercial lead sheathing, the only hope for protection appears to lie in mechanical protection which can be obtained from greases, asphalt and fabric, rubber and fabric, and zinc or steel sleeves at the rings. Beef tallow seems to be the most promising grease and it was given a thorough test; tire tape impedes the mining of the beetle considerably, so several combinations of asphalt and fabric and rubber and fabric were tried; thin steel can not be penetrated, so sleeves of this material were placed around the cable where the rings support it. To make a good practical test of all of these materials a section of cable was selected in an area where past damage had been severe and one ring was treated with tallow, one with fabric, one with a steel sleeve, one left as usual for a check, and so on for several spans.

As will be seen, these experiments gave definite results but it must be remembered that, because of the periodic and variable nature of the attack (i. e., in different localities at different times) the chance for securing, in service tests during one season, any immediate proof of the effectiveness of these protective measures was not very great, and the service tests will need to be followed up for a period of several years.

RESULTS OF EXPERIMENTS IN CALIFORNIA IN 1921.

During 1921 the following experiments with the lead-cable borer were carried on at the Los Gatos Forest Insect Laboratory in the

town of Los Gatos, at Palo Alto, and at Santa Barbara. The work was carried on in cooperation with the American Telephone & Telegraph Co., the Pacific Telephone & Telegraph Co., the Santa Barbara Telephone Co., and the Los Gatos Telephone Co. A total of 6,953 beetles were reared and used in the various experiments. One of the most interesting results obtained was the determination that the beetles are unable to penetrate *pure gum rubber*. Another is the catching of the beetles by placing sticky tree-banding material on the cables.

Cage Experiments.

To determine if possible the attractive effect of varying currents of electricity on the beetles the following experiments were conducted.[14]

Experimental cage.—One of the large cages used in 1920, which contained seven cables 10 feet long suspended from the messenger strands by rings of various types, was again used. An engineer of the Pacific Telephone & Telegraph Co. designed an apparatus which made it possible to use the alternating currents of higher talking frequencies as well as the currents of lower commercial frequencies used in 1920. The idea was to create in these test cables any condition that could occur in the regular commercial cables.

Of the seven cables in the cage, four were connected with the apparatus and three were left "dead." Cable No. 1 had four pairs in parallel tapped to a 1,000-cycle circuit and the far ends shorted; cable No. 2 had four pairs in parallel tapped to a 1,000-cycle circuit and the far ends open; cable No. 3 had four pairs in parallel tapped to a 1,000-cycle circuit and the far ends shorted and connected to the sheath; cable No. 4 had the sheath connected to the 1,000-cycle circuit. Two drops were used, No. 1 for cables 1, 3, and 4, and No. 2 for cable 2. Both drops could be used singly or together and a battery could be switched in or out.

Some beetles were liberated in the main cage and were free to attack any of the cables, charged or dead, while others were confined in smaller cages to the various cables. During the season of five months, April 22 to September 27, 2,714 beetles were liberated in the cage on 24 different occasions of varying climatic conditions. A few slight borings were noted on cables 2 and 3, but as a whole the experiment was without any definite positive result.

Aerial cage.—Two small wire-screen cages were placed around a regular 25-pair commercial cable in Palo Alto. These cages were placed on the cable where it ran through the top of a large acacia tree, which caused varying conditions of light and shade. Each cage inclosed several suspension rings as well as a section of the cable.

[14] All of the officials of the Pacific Telephone & Telegraph Co., the Santa Barbara Telephone Co., and the Los Gatos Telephone Co. cooperated to the fullest extent in the experiments.

On seven different occasions from July 8 to August 8, 268 beetles were placed in each cage. The beetles crawled all over the cable and rings and mated and otherwise acted normally. In a similar cage suspended in the tree and inclosing several sections of oak wood they entered the wood and laid their eggs. In the cable cages, however, they made only a few minor attempts to bore the cable. On one occasion a quantity of alcohol was poured on a section of the cable in an attempt to stimulate them to action, but without effect.

Office cage.—Two screen cages were placed around two different 600-pair commercial cables in the basement of the Palo Alto telephone office. These cables lead directly to the switchboard. On six different occasions from June 30 to September 21, 260 beetles were placed in each of these cages. Only a few minor attempts to bore the cables were made by the beetles.

Battery cage and alcohol cage.—The wire chief of the Palo Alto office of the Pacific Telephone & Telegraph Co. suggested that there might be some slight galvanic action between the galvanized suspension rings and the lead sheath. In order to determine the attractive effect of a slight current on the beetles and also whether they could detect alcohol through the lead sheathing, a small wire-screen cage was made and suspended from the ceiling of the basement by strings.

Two sections of lead cable sheathing about 12 inches long were emptied of the inclosed wires. One was filled with grain alcohol and sealed at both ends, and the other was left empty and sealed at both ends. Both were suspended by strings in the cage. The alcohol-filled cable was suspended just far enough above the bottom of the cage to allow the beetles crawling on the cage to reach it. The empty cable was suspended in a similar manner. One end was attached to a battery which had the other pole attached to the screen of the cage. The idea was that the beetle crawling on the bottom of the cage would complete the circuit as soon as it touched the cable.

During the period from July 22 to August 8, 110 beetles were placed in the cage on three occasions. The cables were removed on August 12 and carefully examined. Each showed a few slight scratches but no definite boring. A strip of heavy paper was placed on the bottom of the cage to give the beetles a smooth foundation from which to bore. Thirty beetles were placed in the cage, and on August 22, 15 more. August 29 the cables were removed and again examined. The alcohol cable was bored twice at one of the sealed ends. One beetle had penetrated to the alcohol and was drowned in its hole. The battery cable had one hole toward the middle, where a beetle or beetles had entered and two holes at one end where beetles had gone out.

The holes were plugged with wax and the cables replaced in the cage with 50 beetles. On September 7, 12 fresh beetles were placed

in the cage. The cables were examined on September 13. No new work was found in the battery cable, but considerable new work was noticed in the alcohol one. Numerous attacks had been made on the underside, two of which had penetrated the lead and were allowing the alcohol to escape. These were filled with wax and the cables returned to the cage. The cage was examined on September 21. There was no new work, but the alcohol had escaped. Thirty-three beetles were placed in the cage and the battery connections removed. On October 6 the cage was examined and most of the beetles were found to be missing. Two more holes were found in the alcohol cable and numerous small borings. Both cables were cut into twos and nine beetles were found inside of the battery cage which had the battery detached September 21. Some were trying to bore out at the ends.

Taking the experiment as a whole, the results are indefinite. One beetle bored a hole into the battery-attached cable and at least six penetrated the alcohol-filled one. During the time the cage was in use, however, 250 beetles were placed in it and practically all of the boring was done by a few beetles from two or three lots. If any particularly attractive condition had been created it seems as though more boring should have been done. The experiment opens up a new field, however, and should be continued this year (1922).

Holes.—To determine if the beetles are attracted to holes already started in the cable by other means, a section of a cable was punctured and partially punctured by a number of holes, some shallow and some nearly through the sheath, and placed in a cage. Forty-five beetles were introduced into the cage on two different occasions. Six males were found in the holes at various times but no females.

Colors.—To determine the attractive effect of colors on the beetles, sections of dead cable and sections of wood were painted in alternating rings of red, yellow, and green and placed in the large experimental cage. Over 1,500 beetles had a chance to attack these, but none did.

Fermentation Experiments.

Alcohol.—To determine the attractive effect of alcohol on the beetles the following experiments were carried on in addition to those mentioned under "Aerial cage" and "Battery cage." Twenty glass vials 11 millimeters by 60 millimeters were placed in a cage. Ten of these were empty and 10 contained grain alcohol. All were closed with cork stoppers. They were placed in the cage in two rows, empty alternating with alcohol-filled, and cork end alternating with glass bottom. Forty-five beetles were placed in the cage on two different occasions. One cork of an alcohol-filled vial was attacked and bored several times and two others slightly bored.

All of these attacks were at the point of contact of the glass with the cork. One cork of an empty vial showed a slight attack well above the glass.

In another experiment two 30 by 100 millimeter vial corks were soaked in alcohol for three days and then placed in a cage with two untreated similar corks and 10 beetles. No attacks were made on any of the corks.

In the laboratory a 30 by 100 millimeter vial filled with alcohol fell on its side and remained there for some time. The cork of this vial was riddled with beetle attacks, at least 12 beetles having bored it.

Oak-bark tea.—Four feet of cable in the "experimental cage" was painted with old oak-bark tea. One hundred beetles were active around it but none appeared to be attracted.

Yeast.—Sections of oak were dipped into various strengths of a yeast dissolved in warm water. Ten beetles were placed with the sections. Apparently these were slightly attracted to the sections dipped in the strongest mixture (2 cakes to one-half quart) and left for the longest time (48 hours).

About all that can be said about these fermentation experiments is that they indicate that at certain times under certain conditions some beetles are attracted. As the conditions of the ferments vary so much and the beetles themselves vary in the same ratio, it is almost impossible to draw reliable conclusions.

Occurrence Experiments.

In order to determine the normal occurrence of the beetles around the regular commercial cables the following experiments were conducted.

Los Gatos.—Four sections of freshly cut oak with the ends dipped in hot paraffin were suspended parallel with the cable in two different locations in Los Gatos. Two sections were suspended near a wood yard which contained beetle-infested wood and the other two about one-half mile away. The sections remained in place from July 25 to October 25. One of the sections suspended near the wood yard was attacked by three different females. The other three sections were not attacked.

Palo Alto.—Similar sections of wood were suspended in the acacia tree close to the cable cages mentioned under "aerial cage" at Palo Alto. No attack was made on these sections. Beetles placed in a small cage with similar sections attacked the sections, so it is reasonable to suppose that if any beetles had been flying near by they would have attacked these sections.

Santa Barbara.—On August 18 about 25 feet of commercial cable at Santa Barbara was covered with a commercial sticky material

used on fly paper and another used for banding trees, about half the length with one and half with the other. The cables were examined about October 1 and a number of insects were found caught. Four of these were adults of the lead-cable borer.

These experiments indicate that the beetles are common enough around the cables to cause the damage accredited to them.[15]

Emergence Experiments.

Table 5 gives the results of emergence experiments conducted at Los Gatos, Calif., in 1921.

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[15] During 1922, commercial sticky material used on fly paper was placed upon the aerial telephone cables in use in four cities; in each city several localities were selected. This sticky material was placed on the cables in May and June and remained until the season was over in September.

In San Jose, 50 sheets were placed upon the cables, in 5 places, 10 sheets to a place; these sheets were about 15 inches long. Near the tannery in Santa Clara 2 beetles were caught; at Station No. 2, 1 beetle; across from the wood yard where thousands of beetles were reared (Station No. 3) 1 beetle was caught; Station No. 4, no beetles; Station No. 5, 1 beetle; or a total of 5 for San Jose.

In the other three cities, the Pacific Telephone & Telegraph Co. placed the sticky material upon the cables. In Los Angeles, 8 localities were selected and from 1 to 8 sheets placed on the cables; only 3 beetles were obtained and these came from locality B with 7 sheets on the cables.

In Santa Rosa, 4 localities with 6 sheets each were selected; 1 beetle was found on the sheets from locality *a*.

In Monterey, 5 localities were selected, 3 in Monterey, 1 at Carmel Hill, and 1 at Salinas; Monterey No. 4 caught 1 beetle on 8 sheets on the cables and Salinas No. 1 caught 1 beetle on 8 sheets on the cables.

Full data were not received from the telephone company in time to include in this paper.

The results seem to indicate that all along the Pacific coast a few beetles are continually going to the cables in all localities, but nowhere do they appear in numbers. The damage is only incidental and there appears to be no special attraction in the cables to draw the beetles. If the beetles get down between the rings and the cable, the contact causes them to bore; otherwise they crawl or fly off without doing any damage.

TABLE 5.—*Emergence of beetles of the lead-cable borer from infested sections of wood through protective coverings; Los Gatos, Calif., 1921.*

Experiment.	Covering used.	Number of beetles emerged from wood.	Stopped.		Penetrated.	
			Beetles.	How stopped.	Beetles.	What.
	Stearin 25 per cent and paraffin 75 per cent:					
A	1/32 inch thick	43	2	By covering	41	Covering.
B	Do	[1] 0	0		0	
C	1/4 inch thick	39	0		39	Do.
D	1/32 to 1/4 inch thick	7	2	By thick covering	5	1 through thick covering, 4 through thin covering.
E	1/32 inch thick	43	0		43	Covering.
F	Do	51	3	By covering	48	Do.
	Stearin:					
A	1/16 to 1/4 inch thick	13	0		13	Do.
B	Do	23	0		23	Do.
C	1/8 to 1/2 inch thick	8	5	By thick covering	3	Thin covering.
D	1/32 inch thick	64	0		64	Covering.
E	Do	21	0		21	Do.
	Chlorinated naphthalene, No. 1001:					
A	1/32 to 3/8 inch thick	35	17	By thick covering	18	4 through thick covering, 14 through thin covering.
B	1/32 to 1/8 inch thick	25	0		25	6 through thick covering, 19 through thin covering.
C	1/32 inch thick	82	0		82	Covering.
	Finishing wax:					
A	1/16 to 1/4 inch thick	8	0		8	Do.
B	Do	[1] 0	0		0	
C	Do	[1] 0	0		0	
D	1/16 inch thick	6	0		6	Do.
E	Do	1	0		1	Do.
F	1/32 to 1/16 inch thick	20	0		20	4 through thick covering, 16 through thin covering.
	Saturating wax:					
A	1/32 to 1/16 inch thick	14	0		14	Covering.
B	Do	47	3	By covering	44	Do.
C	Do	[1] 0	0		0	
D	1/16 inch thick	14	2	By covering	12	Do.
A	Beef tallow, cold, 1/4 inch thick	39	0		39	Do.
	Splicing compound "X":[2]					
A	Fabric side away, 3 to 4 thicknesses	16	16	11 by 1, 5 by 2	5	5 through 1, 0 through 2.
A1	Compound only, 3 to 4 thicknesses	22	22	5 by 1, 15 by 2, 2 by 3	17	17 through 1, 2 through 2, 0 through 3.
B	Fabric next to wood, 4 thicknesses	27	27	15 by 1, after penetrating fabric; 12 by 2, after penetrating fabric.	12	12 through 1, 0 through 2.
B1	Fabric only, 4 thicknesses	16	[3] 2	0 by 1, 1 by 2, 1 by 3, 0 by 4	16	16 through 1, 13 through 2, 12 through 3, 12 through 4.

	Splicing compound "Y":					
A	Fabric side away, 2 to 3 thicknesses	4	4	By covering	0	
A1	Compound only, 2 to 3 thicknesses	25	23	6 by 1, 14 by 2, 3 by 3	19	19 through 1, 5 through 2, 2 thorugh 3.
B	Fabric next to wood, 3 to 4 thicknesses	21	21	9 by 1, 11 by 2, 1 by 3	12	12 through 1, 1 through 2, 0 through 3.
B1	Fabric only, 3 to 4 thicknesses	9	0	0 by 1, 0 by 2, 0 by 3, 0 by 4	[4] 9	9 through 1, 8 through 2, 8 through 3, 6 through 4.
	Splicing compounds "X" and "Y," rolled together:					
A	Fabric next to wood, 6 to 8 thicknesses	39	39	6 by 1 X, 26 by 2 Y, 6 by 3 X, 1 by 4 Y	33	33 through 1, 7 through 2, 1 through 3, 0 through 4.
A1	Do	38	38	5 by 1 Y, 21 by 2 X, 12 by 3 Y	33	33 through 1, 12 through 2, 0 through 3.
B	Compound only, 6 to 8 thicknesses	22	22	10 by 1 X, 12 by 2 Y	12	12 through 1, 0 through 2.
B1	Do	22	22	12 by 1 Y, 10 by 2 X	10	10 through 1, 0 through 2.
C	Fabric only, 6 to 8 thicknesses	13	[5] 4	0 by 1, 0 by 2, 0 by 3, 2 by 4, 1 by 5, 1 by 6, 0 by 7, 0 by 8.	13	13 through 1, 13 through 2, 13 through 3, 11 through 4, 10 through 5, 9 through 6, 3 through 7, 3 through 8.
C1	Do	9	2	0 by 1, 0 by 2, 0 by 3, 1 by 4, 0 by 5, 0 by 6, 1 by 7, 0 by 8.	9	9 through 1, 9 through 2, 9 through 3, 8 through 4, 8 through 5, 8 through 6, 7 through 7, 7 through 8.
A	2-inch black friction tape, wound spirally, 1 to 7 thicknesses.	19	[6] 16	1 by 1, 1 by 2, 4 by 3, 6 by 4, 1 by 5, 3 by 6.	18	18 through 1, 15 through 2, 10 through 3, 4 through 4, 3 through 5, 0 through 6.
A1	Black friction tape, 2 thicknesses, crossed	24	[7] 8	2 by 1, 6 by 2	22	22 through 1, 4 through 2.
B	Spread friction tape, No. 1727, wound spirally, 1 to 6 thicknesses	11	[8] 8	0 by 1, 1 by 2, 1 by 3, 1 by 4, 3 by 5, 2 by 6.	11	11 through 1, 10 through 2, 9 through 3, 6 through 4, 3 through 5, 1 through 6.
C	Calendered friction tape, No. 1716, wound spirally, 2 to 4 thicknesses.	8	[9] 5	0 by 1, 1 by 2, 3 by 3, 1 by 4	8	8 through 1, 7 through 2, 3 through 3, 1 through 4.
A	Black rubber insulating compound, 1 to 2 thicknesses	47	[10] 8	0 by 1, 8 by 2	47	47 through 1, 25 through 2.
B	Red rubber insulating compound, 1 to 4 thicknesses	55	[11] 47	0 by 1, 6 by 2, 16 by 3, 25 by 4	55	55 through 1, 47 through 2, 29 through 3, 4 through 4.
C	30 per cent rubber insulating compound	73	73	63 by 1, 10 by 2	10	10 through 1, 0 through 2.
D	Pure gum rubber, 7 thicknesses	37	[12] 37	37 by 1	0	

[1] None emerged at area covered.
[2] Several individual experiments were conducted with two commercial splicing compounds designated as "X" and "Y." Small strips were used over adults which seemed ready to emerge. In some cases the fabric was placed next to the wood and in other cases the compound was so placed. In all cases the beetles emerged.
[3] Two escaped after penetrating first thickness.
[4] One escaped after penetrating first thickness, and 2 after penetrating third.
[5] Six escaped at sixth thickness.
[6] Two escaped at first thickness and 1 at second.
[7] Twelve escaped at first thickness.
[8] Two escaped at third thickness.
[9] One escaped at second thickness and 1 at third.
[10] Fourteen escaped.
[11] Two escaped at first thickness and 2 at second.
[12] Eight of the 37 got one-half through first thickness; 11 got about one-fourth through first thickness.

Protection Experiments.

Steel sleeves.—To determine the protective value of steel sleeves placed around the cables within the suspension rings a number of these were placed on a commercial cable at Palo Alto. As no attack was made on the cable in that locality the results are negative.

P. & B. paint.—Many of the old cables used in the city of Santa Barbara have been coated with P. & B. paint. In numerous cases this paint gathered on the underside of the cables, which allowed the beetles to obtain a foothold for boring from it.

Weathering Tests of Protective Materials.

Table 6 gives a list of materials which might be used on the cables to keep the beetles from boring into them. It also shows how the

Table 6.—*Weathering tests of materials applied to cables for protection against the lead-cable borer; Los Gatos, Calif., 1920–21.*

Material.	Date examined.	Odor	Color.	Consistence.	Weathering condition.
A	Nov. 30, 1920	Slightly oily or varnishy.	Dark brown, nearly black.	Firm where thinly applied, soft where thickly applied.	Does not hold evenly; has dried out and hardened, except where heavily applied.
	Nov. 24, 1921	Oily	Yellowish brown	Flaky and crumbly	Very little grease left.
B	Nov. 30, 1920	Slightly oily.	Lemon yellow	Soft and pliable	Holds well, has not deteriorated.
	Nov. 24, 1921	Oily	Light yellow	Soft and fairly pliable, smooth.	Still greasy, holds evenly, has deteriorated, but is best of greases.
C	Nov. 30, 1920	Slightly oily.	Yellow brown	Soft and fairly pliable.	Holds well; has deteriorated more than B.
	Nov. 24, 1921	Oily	Brownish yellow.	Slightly greasy, flaky.	Some grease in heavy portion, flaky at ends.
D	Nov. 30, 1920	do	Dirty white where thin.	Soft	Not as good as B and C, but better than A; has deteriorated considerably.
	Nov. 24, 1921	do	Yellow to dark brown.	Firm but pliable, not flaky.	Fairly even where thin; some grease remains.
E	Nov. 30, 1920	Musty	Nearly black	Fairly soft	Has hardened somewhat.
	Nov. 24, 1921	do	Dark brown	Powdery, no grease left.	Badly deteriorated.
F	Nov. 30, 1920	Tallowy	Milky white	Soft and pliable	Like day of application.
	Nov. 24, 1921	do	Dirty white	Firm	Holds well, especially where thick.
G	Nov. 30, 1920	Slight paraffin.	Colorless	Firm but pliable	Like day of application.
	Nov. 24, 1921	do	do	Soft and even	Very good.
H	Nov. 30, 1920	Strong naphthaline.	Creamy yellow	Hard, waxy, flakes off where thinly applied.	Appears very good.
	Nov. 24, 1921	Naphthaline.	Yellowish white.	Like firm laundry soap	Very good.
I	Nov. 30, 1920	No odor	Dark brown	Firm, uneven	Some deterioration.
	Nov. 24, 1921	do	do	Firm, hard, waxy	Poor.
J	Nov. 30, 1920	Tarry	Nearly black	Hard where thin, sticky where thick.	Like day of application.
	Nov. 24, 1921	do	do	do	Has changed very little.
K	Nov. 30, 1920	No odor	Black	Hard and smooth, velvety.	Like day of application.
	Nov. 24, 1921	do	Velvety black	Firm and even	Slight deterioration.

weather affected them. The test cable was placed in position September 29, 1920, and thoroughly examined November 30, 1920, and November 24, 1921. The materials to be tested were placed on the cable at the points where it was suspended by the rings. The tallow and

waxes were heated and poured onto the cable; the greases were spread on with a paddle, and the tar and paint were applied with a brush. The materials used were (A to E) commercial greases or petroleum compounds; (F) a mixture of refined paraffin, 50 per cent, and tallow, 50 per cent; (G) refined paraffin; (H and I) two chlorinated naphthalene compounds Nos. 1001 and 1008; (J) pine tar; and (K) P. & B. paint.

The records indicate that the greases (A–E) with the possible exception of B, do not weather as well as the waxes (F–I) and the paints (J and K). The paraffin (G) appears to have held its original qualities best, with H, F, K, J, and I following in the order given.

RESULTS OF EXPERIMENTS IN CALIFORNIA IN 1922.

During the season of 1922 bitumastic enamel, animal gall, pine tar, sealing wax, turpentine and rosin (1 quart to 1 pound), several preparations of mineral paint, pure rubber, tin foil, copper foil, and thin copper sheeting were experimented with as repellents. The only materials that stopped the beetles were the copper foil and copper sheeting and the rubber. Numerous beetles tried the copper but none succeeded in penetrating it. Six beetles out of 32 penetrated one thickness of the rubber and 2 of these emerged. None succeeded in penetrating more than one thickness.

So far as can be determined none of the substances have any repellent value, for the beetles enter wood through them as well as emerge through them. It was felt that the animal gall would repel them, but they attack the wood through it and also through the mineral paints.

Acetic acid and tannic acid, as well as the alcohol, show some attraction to the beetles. One of the telephone men brought in some specimens of Scobicia which he found entering a wine cask.

In the attempt to determine the cause of the beetle's attacking the cable no definite conclusions have been reached. The authors believe that the beetle bores the cable because it finds itself closely confined between the cable and the suspending ring, but they do not believe that it can be proved. If it was drawn to the cable by any other attraction it would have to go to this same point to be able to get a foothold from which to bore, and this makes the proof of the theory difficult. The authors have tried the lead, light, heat, electricity, and color as attractants with negative results; but when two pieces of lead are brought closely together, as by a fold, or a glass plate is placed on a sheet of lead and beetles put between, boring takes place.

It was found that adults of *Scobicia declivis* would attack corks treated with a solution of tannic acid and also those treated with a

solution of acetic acid. Oak wood, the normal host, contains tannin and acetic acid.

Below is an analysis, by the Bureau of Chemistry of this department, of a section of oak wood from California.

TABLE 7.—*Analysis of a section of oak wood from California.*

Determination.	As received.	Moisture-free basis.
	Per cent.	*Per cent.*
Moisture	20.36	.....
Total solids	6.57	8.25
Soluble solids	6.29	7.93
Insolubles	0.28	0.32
Non-tans	4.20	5.27
Tannin	2.09	2.66

As nearly as could be judged, catechol and pyrogallol tans were present in nearly equal amounts, pyrogallol probably predominating. Pyrogallol was shown definitely by the acetic acid-lead acetate test. The iron-alum test was rather indefinite. Catechol was shown by the bromide test and by the formaldehyde test.

THE METAL-PENETRATING ABILITY OF THE INSECTS ASSOCIATED WITH THE CABLE BORER.

During the study of the penetrating power of the cable beetle numerous records were made on the penetrating ability of the associated insects and a few other species.

The roundhead *Xylotrechus nauticus* Mann. was able to penetrate all of the alloys used, the carborundum-coated lead, copper-coated lead, and building paper. (Pl. IV, Fig. 4.) It penetrated as many as five thicknesses of lead-antimony alloy and seven sheets of building paper. It made no impression on the sheet zinc or sheet steel. Another roundhead, *Neoclytus conjunctus* Lec., penetrated six thicknesses of the lead-antimony alloy and four of pure lead. It made a slight impression on the sheet zinc, but none on the sheet steel. A third roundhead, *Phymatodes nitidus* Lec., seemed unable to penetrate the carborundum-coated lead, but did penetrate one thickness of the lead-antimony alloy and four coats of spar varnish. The fourth roundhead, *Callidium pseudotsugae* Fisher, made only a slight impression on the lead. One Xylotrechus larva penetrated five thicknesses of copper-coated lead and three coats of spar varnish. A bostrichid larva, *Polycaon stoutii* Lec., penetrated one thickness of copper-coated lead but was stopped by the carborundum-coated lead. A few powder-post beetles, *Lyctus planicollis* Lec., penetrated one thickness of lead-antimony alloy and two thicknesses of lead-antimony and lead-tin together, but many beetles of this species did not seem able to penetrate any of the alloys or the carborundum-coated lead. The predatory clerids were unable to make any impression on the alloys.

SUMMARY AND CONCLUSIONS.

Although the fact is rather astonishing to the layman, insects do considerable damage to various manufactured articles of metal throughout the world. One of the most important of these injuries is that to the lead sheathing of telephone cables in California. This consists of circular holes about 0.1 inch in diameter which penetrate the sheathing. These allow the entrance of moisture, which causes a short circuiting of the wires and the resulting stoppage of service to the public.

The insect causing this trouble is a "powder-post" beetle belonging to the family Bostrichidae. Its technical name is *Scobicia declivis* Lec. Normally it lives in the wood of the live oak and other trees as an egg, larva, pupa, and young beetle for about one year. Periodically some beetles attack the cables during the summer season and cause some damage. Practically all of the boring is done near the point of contact of the cable and the rings which suspend the cable from the messenger strand which supports it. This is done because the beetle must have a foothold from which to attack the cable. It obtains the desired foothold by bracing itself against the ring. As moisture is the immediate cause of the trouble, the damage usually fails to become apparent until the rainy season commences, when there is an accumulation of "troubles" to be located and repaired within a short time.

The experiments conducted to date indicate that the beetle is able to penetrate any lead alloy used as a cable sheathing or any poison or repellent placed on the sheathing. Probably it is able to penetrate the poisons because it does not feed as it bores through. Theoretically, if any grease or grease compound which will soften in the sun when the beetle is most active is placed on the rings it will stick to the beetle and suffocate it when it tries to bore into the cable. Beef tallow appears to be the best grease for this purpose. Layers of friction tape impede the boring and thin sheets of copper, zinc, and steel prevent it. Sleeves of these metals can be placed around the cable at the rings, but the cost probably would be too great for general use. At the present time tallowing the rings is the most promising method of control. During the season of 1921 it was found that the beetles were unable to penetrate pure gum rubber.

No definite results were obtained from experiments with the various types of suspension rings. The beetles in the cages would not enter at any of them. It is believed that the new type of ring, made of flattened steel-wire stock, galvanized, which the telephone companies are now installing, is better from the standpoint of preventing attack by the beetle than the older one.

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INSECTS ATTACKING OR PENETRATING METALS.[16]

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(2) MACLEAY, W. S.

1821. HORAE ENTOMOLOGICAE. v. 1, pt. 2, p. 161–524. London.

Page 193: Heteropterous Coleoptera feed on inorganic matter.

(3) KIRBY, WILLIAM, and SPENCE, WILLIAM.

1822. AN INTRODUCTION TO ENTOMOLOGY . . . (ed. 4), v. 1, 513 p., 2 pl. London.

Page 235: Larva of *Callidium bajulus* damages wood of roofs or houses in London; the adult emerges through sheet lead ⅛ inch thick.

(4) KIRBY, W.

1823. ON ANIMALS RECEIVING THEIR NUTRIMENT FROM MINERAL SUBSTANCE. *In* Philos. Magaz. and Jour., v. 61, no. 297, p. 3–4.

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(5) SOCIÉTÉ ENTOMOLOGIQUE DE FRANCE.

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Page lxxvi: Observations de M. Audouin sur la faculté que possèdent les Callidies de ronger des crops très durs. M. Émy: "Toitures en plomb . . . percées . . . par des larves de Bostriches" [Roofing penetrated].

(6) ENTOMOLOGICAL SOCIETY OF LONDON.

1839. JOURNAL OF PROCEEDINGS. *In* Trans. Ent. Soc. London, v. 2.

Page lxxxiii: Observations of W. Sells on the perforations of the larvæ of *Sirex juvencus*.

(7) DEBRÊME.

1844. COMMUNICATION. *In* Ann. Soc. Ent. Fr. 2 sér, t. 2, Bul. 6 mars.

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(8) SOCIÉTÉ ENTOMOLOGIQUE DE FRANCE.

1844. ANNALES, 2 sér., t. 2, Bul. 20 mars.

Page xxiv–xxvi: Notice sur des clichés typographiques percés par des insectes (*Apate capucina*) et sur des lames de plomb percées de Cetoines. [Stereotype plates.]

(9) MUNFORD, G.

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(10) HENSLOW, J. S.

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(11) ENTOMOLOGICAL SOCIETY OF LONDON.

1850–1851. PROCEEDINGS, Sept. 2, 1850, Trans. Ent. Soc. London, new ser. v. 1, p. 34–35.

Notice of *Monohammus sutor* boring into lead.

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[16] Prepared by Dr. T. E. Snyder with the assistance of Dr. E. A. Schwarz and Dr. F. H. Chittenden, of the Bureau of Entomology.

(12) SOCIÉTÉ ENTOMOLOGIQUE DE FRANCE.
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(13) HAGEN.
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(14) KOLLAR, V.
1854. BEMERKUNG HIERZU [Entomol. Notiz., Hagen (14)]. *In* Verhandl. Zool. Bot. Vereins Wien, bd. 4, Sitzungsber., p. 113–114.
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(15) LINNEAN SOCIETY OF LONDON.
1855. PROCEEDINGS, Nov. 18, 1851, p. 153–154.
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(16) ———
1857. ÜBER DAS INSECT [SIREX JUVENCUS], WELCHES DEN FRANZÖSEN WÄHREND DES FELDZUGES IN DER KRIM DIE BLEIKUGELN DURCHGEBOHRT HAT; NEBST EINER MITTHEILUNG ÜBER EINE ANALOGE ERSCHEINUNG IN WIEN. *In* Verhandl. Zool. Bot. Vereins Wien, bd. 7, Sitzungsber., p. 153–155.

(17) VAILLANT.
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(18) MOTSCHULSKY, V.
1858. SUR L'INSECTE QUI A PERFORÉ LES BALLES DE PLOMB DE L'ARMÉE FRANÇAISE EN CRIMÉE. *In* C. R. Acad. Sci. Inst. France, t. 46, no. 25, p. 1211–1213.
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(19) SOCIETÉ ENTOMOLOGIQUE DE FRANCE.
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(20) NIEDERRHEINISCHEN GESELLSCHAFT IN BONN.
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(23) ENTOMOLOGICAL SOCIETY OF LONDON.
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(24) DEVOE, F. W.
1888. THE BEETLE, ZOPHERUS MEXICANUS SOL., CUTTING METAL. *In* N. Y. Microscopical Soc., v. 4, no. 3, July, p. 145–147, pl. 13–14.

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(26) [RILEY, C. V.]
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(28) SCIENTIFIC AMERICAN.
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(33) [SCHWARZ, E. A.]
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(38) ESSIG, E. O.
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1919. INSECTS DAMAGING LEAD. *In* Ent. Mo. Mag., v. 55, no. 667 (3rd ser., v. 5, no. 60), p. 278–279.

(47) MITSUHASHI, S.
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(48) UNITED STATES DEPARTMENT OF AGRICULTURE.
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(49) [ANONYMOUS.]
1919. CAN EAT THROUGH LEAD. *In* Field and Farm, 34th year, whole no. 1734, p. 10. May 10.

Scobicia (*Sinoxylon*) *declivis.*

(50) BANKS, Nathan, and SNYDER, Thomas E.
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(51) [BROWN, W. H. (ed.).]
1920. TELEPHONE CABLES DAMAGED BY WOOD BORERS. *In* Agr. Gazette N. S. W., v. 31, pt. 5, p. 344. May.

A suspension of the telephone service was caused by water reaching the wire through small holes bored by the beetle, *Bostrychus cylindricus.* Cables have frequently been attacked in the same way, and an instance of similar injury due to another Bostrychid has already been noted (Froggatt, 45). *B. cylindricus* is one of the commonest Australian wood-boring beetles, attacking all kinds of timber; but the larvae usually feed and pupate in the sapwood. The beetle has been recorded as damaging empty wine-casks. The boring in lead seems to be casual, and no practical method of dealing with it has presented itself, except to destroy any poles, etc., in which the larvae were found to be breeding in any numbers.

(52) CHILD, Allen P.
1920. THE "SHORT-CIRCUIT" BUG OF CALIFORNIA. *In* Scientific American, v. 123, no. 26, Dec. 26, p. 637. 1 fig.

Scobicia declivis.

(53) SCOTT, Hugh, and LAING, F.
1920. INSECTS DAMAGING LEAD AND OTHER METAL-WORK. Insects damaging lead: Supplementary note. *In* Ent. Mo. Mag., v. 56, 3rd ser. v. 6, No. 61, no. 668, p. 10–12. January.

(54) SNYDER, Thomas E.
1920. THE LEAD CABLE BORER. *In* Jour. Wash. Acad. Sci., v. 10, no. 20, p. 580. Dec. 4. (Author's abstract, lecture March 20, 1920, Proc. Biological Soc. Wash., 609th meeting.)

General discussion of the damage to metal by boring insects and especially by *Dermestes vulpinus* Fab. to tubular lead telephone fuses and by *Scobicia declivis* Lec. to the lead sheathing of aerial telephone cables in California. Discussion of remedies and preventives; an effective *permanent* preventive has not yet been discovered.

(55) FELT, E. P.
1922. WORMY TIMBER COSTLY. *In* Jour. of Forestry, v. 20, no. 3, p. 321.

Timbers infested by horntails in new sulphuric acid factory near Saarau, Silesia; adults emerged through lead floor plates, causing loss of 100,000 marks.

THE CALIFORNIA LEAD-CABLE BORER, SCOBICIA DECLIVIS LEC.[17]: BIOLOGY AND TAXONOMY.

(56) DUFTSCHMID, CASPAR.
1825. FAUNA AUSTRIAE, pt. 3, 289 p. Lenz and Leipzig.

Page 85: Sinoxylon described.

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[17] Prepared by Dr. T. E. Snyder with the assistance of Dr. E. A. Schwarz, Dr. F. H. Chittenden, and Mr. W. S. Fisher, of the Bureau of Entomology.

(57) SOCIÉTÉ ENTOMOLOGIQUE DE FRANCE.
1845. ANNALES, 2 sér., t. 3, Bul.

Page xvii: Xylopertha described by Guérin-Méneville.[18]

(58) LECONTE, JOHN T. (i. e. John L.)
1860. REPORT UPON INSECTS COLLECTED ON THE SURVEY. ZOOLOGY 47TH PARALLEL. *In* Reports of explorations and surveys . . . for a railroad from the Mississippi River to the Pacific Ocean. 1853–1855. v. 12, bk. 2, pt. 3, no. 1, 72 p., 2 pls.

Page 48: *Sinoxylon declive:* Original description.

(59) HORN, GEORGE H.
1878. REVISION OF THE SPECIES OF THE SUBFAMILY BOSTRICHIDAE OF THE UNITED STATES. *In* Proc. Amer. Phil. Soc., v. 17, p. 540–592.

Same generic and tribal arrangement of *S. declive* as LeConte.

(60) COMSTOCK, J. HENRY.
1881. REPORT OF THE ENTOMOLOGIST FOR 1880. *In* Ann. Rept. U. S. Dept. Agr. 1880, p. 235–373.

Page 274–275: Wine cask borers. "In India *Tomicus* [*Xyleborus*] *monographus* is stated by Morse to do great damage by drilling holes in malt-liquor casks, the custom being to destroy the beetles by submerging the casks in boiling water. In California *Sinoxylon declive* Lec. has similar habits. Oak, chestnut, pine, whitewood, and eucalyptus wood have all been used in making casks with a view to discovering some substance which would prove distasteful to the beetles, but without success. Dr. Rivers, curator to the Museum of the University of California, has, however, succeeded in making a cask apparently beetle-proof by saturating the outside with a strong solution of alum water applied while hot, and, as soon as dry, painting with linseed oil. The cask thus treated remained unharmed by the beetles while others were riddled."

(61) RIVERS, J. J.
1886. CONTRIBUTIONS TO THE LARVAL HISTORY OF PACIFIC COAST COLEOPTERA. Bul. Calif. Acad. Sci., v. 2, no. 5, p. 63–72.

Page 68: "*Sinoxylon declive* Lec. Any dead tree or unpainted wood, very partial to wine casks and oak barrels. The depredations are done by the beetle while boring for a suitable place to deposit its eggs. Its burrow is straight across the grain of the wood, reaching the interior of the cask, causing waste and deterioration of the contents. Hot solution of alum applied to the outside of the casks will prevent boring."

(62) ———
1887. THE OAKS OF BERKELEY AND SOME OF THEIR INSECT INHABITANTS. 12 p. Sacramento.

Page 11: Attacking dry lumber, particularly oak, and especially oaken wine casks, "inflicting a loss of many thousands of dollars annually to the wine interest."

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[18] Xylopertha was described by Guérin-Méneville (*57*), and Lesne in his monograph of the Bostrichidae (*66, p. 528–529*) includes three species, as follows: *crinitarsis* Imb., from Africa; *picea* Ol., from Africa and also imported into South America; and *scutula* n. sp., from Africa.

Casey (*65*) places *declivis* Lec. in the genus Xylopertha with the following remarks: "*Xylopertha* is confined, as might be expected, to the subsiberian fauna of the Pacific coast, where it is represented by *bidentata, declivis* and *suturalis,* hitherto placed in *Sinoxylon,* which genus has the two basal joints of the antennal club short and transverse."

In 1900, Lesne (*66, p. 584–587*) erected the genus Scobicia and included the following species: *pustulata* Fabr., *barbata* Woll., *barbifrons* Woll., *chevrieri* Villa, *ficiola* Woll., *suturalis* Horn, *declivis* Lec., and *bidentata* Horn. The genus is distributed through North, Central, and South America, Mediterranean regions of Europe and Africa, Egypt, Syria, Madeira, and Canary Islands.

(63) COQUILLETT, D. W.
1892. NOTES ON THE HABITS OF SOME CALIFORNIA COLEOPTERA. *In* U. S. Dept. Agr., Div. Ent., Insect Life, v. 4, nos. 7 and 9, p. 260–262, March.

Notes on hosts and biology of *Sinoxylon declive.*

(64) WICKHAM, H. F.
1895. ON THE LARVAE OF LUCIDOTA, SINOXYLON, AND SPERMOPHAGUS. Iowa Univ. Bul. Lab. Nat. Hist., v. 3, no. 3, p. 31–35, 1 pl.

Figure and description of the larva of *Sinoxylon declive.*

(65) CASEY, THOS. L.
1898. STUDIES IN THE PTINIDAE, CIOIDAE AND SPHINDIDAE OF AMERICA. *In* Jour. N. Y. Ent. Soc., v. 6, no. 2, p. 61–93.

Page 67: Places *declivis* Lec. in genus Xylopertha.

(66) LESNE, L.
1900. RÉVISION DES COLÉOPTÈRES DE LA FAMILLE DES BOSTRICHIDES. 4e MÉMOIRE (1). BOSTRYCHINAE SENS STRICT.—II LES XYLOPERTHA. *In* Ann. Soc. Ent. France, v. 69, p. 473–639. Paris.

Page 597–599: *Scobicia* [*Sinoxylon, Xylopertha*] *declivis* Lec., host trees, geographical distribution—Scobicia described.

(67) FALL, H. C.
1901. LIST OF THE COLEOPTERA OF SOUTHERN CALIFORNIA. . . . Calif. Acad. Sci., Occasional Papers, v. 8, 282 p.

Page 133: *S. declive,* Pomona, August and September, numerous specimens taken on windows of a winery; one taken on San Nicolas Island.

(68) ESSIG, E. O.
1915. INJURIOUS AND BENEFICIAL INSECTS OF CALIFORNIA. (2nd ed.) Suppl. to Monthly Bul., Calif. State Comm. Hort., v. 4, no. 4. 541 p, 503 figs.

Page 239, footnote 142: Hosts and abundance noted.

APPENDIX.

TAXONOMY AND MORPHOLOGY OF THE LARVAL STAGES OF SCOBICIA DECLIVIS LECONTE.

By Adam G. Böving.

Scobicia declivis LeConte belongs, according to the characters of the larval stages, to the family Bostrichidae. In the recently published Catalogue of the Coleoptera of America North of Mexico, 1920, by Charles William Leng, the genera Polycaon and Psoa are placed in the tribe Psoini of the Bostrichidae but, according to the larvæ, these genera form, together with the genus Stephanopachys (species investigated: *S. substriatus* Payk. and *S. pacificus* Csy.), which Leng places in the tribe Bostrichini, a well defined family, the Psoidae. This latter family is close to the Lyctidae and, like this family, distinct from the Bostrichidae by having a strong epipharyngeal chitinization, a mandible with a large pseudomolar process, and a large fleshy retinaculum. The larvæ of the other genera listed by Leng in the Bostrichidae substantiate the correctness of his conception of that family.

The larvæ of the Bostrichidae (in the present limitation) may be characterized as follows:

Bostrichidae.[19]

Habitus: Generally rather small, whitish, fleshy. Cyrtosomatic (curved like a scarabaeid larva) in all stages except the first in which it is orthosomatic (straight, with dorsal and ventral surfaces approximately of the same size). Legs, or in first stage rudiments of legs, present; no movable claw separated from tarsus. With plicate, never shield-bearing thoracic and abdominal terga. Ampullæ not present; terga never asperate, with or without soft hairs. Ten visible abdominal segments. Ninth abdominal segment well developed, rounded, unarmed in all stages, except the first in which it is armed with an unpaired, chitinous, mucronate tail appendage or spur. No paired cerci. Tenth abdominal segment small, entirely below ninth; anal opening longitudinal.

Head capsule: Head deeply retracted into prothorax, porrect; with subrectangular outline, free portion subglobular. Occipital foramen ventral and opposite frontal region. Frons indistinct; clypeus and labrum present, labrum movable. Epicranium with rather short and curved hypostoma between mandibular condyle and end of cardo; part behind cardo large. Definite gular region not developed, submentum and the prothoracic presternal skin continuous.

Buccal cavity: Hypopharyngeal bracon absent. Hypopharynx fleshy; maxillular areas elongate, soft, each with a longitudinal series of setæ. Epipharynx soft.

Tentorium: Broad and strong.

Ocelli: Not developed.

Antenna: Of medium size or small.

Mouthparts: Mandible gouge-shaped, inner surface subtetragonal, neither with a true molar structure nor with pseudomolar process; no retinaculum; no accessory mandibular condyle. Ventral mouthparts somewhat retracted. Maxillary articulating area present. Cardo flat, quadrangular, not divided. retracted below stipes. Stipites maxillæ anteriorly convergent, connected with maxillary articulating area and hypostoma. Maxillary mala divided into a

[19] This family characterization, as well as the taxonomic remarks given above, is part of a joint study on the characterization of the coleopterous families according to their larval stages, undertaken by Dr. F. C. Craighead and the author.

large, fleshy, hairy outer lobe (galea?) and a stylus-like process (lacinia?). Palpiger maxillæ large, conical, jointlike. Palpus maxillaris two-jointed. Submentum large, separated from mentum by indistinct line. Mentum laterally free or almost free. Stipites labii fused; no distinct palpiger labii; chitinous, narrow, transverse line between stipites labii and mentum. Ligula (united labial malæ) present, ventrally and dorsally undivided.

Thorax: Prothorax dorsally simple; with oblique chitinous rod imbedded laterally in tergum above and in front of first spiracle. Mesothorax and metathorax dorsally duplicate. No hypopleural chitinization at base of legs. Legs, when well developed, of medium size, four-jointed, hairy, with tarsus claw-shaped and concavity facing forward, widely separated by intermediate broad sternum.

Abdomen: Typical (anterior and median) segments dorsally triplicate.

Spiracles: Bilabiate; first spiracle above anterior margin of mesosternum, somewhat larger than the following eight abdominal spiracles, which are all of same size, all lateral, and all placed at lower margin of the terga.

Habits: Wood-boring and wood-feeding.

Relationship to other families: Close to the larvæ representing the Anobiidae, Ptinidae, Psoidae, and Lyctidae. Also connected with the Donaciidae as well as with the Sagridae and Bruchidae by identity of several important morphological structures. The peculiar adaptation of the maxillary mala for sap-sucking in the Donaciidae can, through the construction of this part in the Plateumarini, be derived directly from the stylus-bearing mala in the Bostrichidae. This characteristic stylus formation occurs also in all the Dermestidae. In several genera of this latter family is also found a thick interior enforcement of the mandibular biting surface which corresponds to a similar development in the mature bostrichid larva.

Scobicia declivis Leconte.

(Larvæ of different stages in U. S. National Museum, Washington, D. C., labeled Hopk. U. S. 16178a4; from Los Gatos, Calif.; collected and reared from eggs by R. D. Hartman.)

The larva of *Scobicia declivis* has six stages. In the first stage several characters are exhibited deviating from those hitherto considered typical in bostrichid larvæ. A full description will be given of only the mature larva and this description will precede the references to the other stages.

GENERAL DESCRIPTION OF MATURE LARVA.

Pl. I, Figs. 1–16; Pl. II, Figs. 17–32.

Length of larva: About 10 millimeters, width 2.50 millimeters. Straight line between head and anus, when larva is curled, 6.85 millimeters. Length of the combined thoracic segments in proportion to length of the combined abdominal segments about as 1 : 2½ (measured on imaginary lateral line through the spiracles). Largest vertical diameter of head in proportion to largest vertical diameter of prothorax, about as 1 : 3.

Head capsule (Pl. II, Figs. 17–19): Formed by fusion of frons and epicranium; elongate, subrectangular with rounded corners, twice as long as wide; almost two-thirds retracted into prothorax; whitish with heavy dark brown chitinization anteriorly on each side. This chitinization is constituted by the lateral part of epistoma (*e*, Pl. II, Fig. 17), the entire pleurostoma (*p*, Pl. II, Fig. 21), the entire hypostoma between mandibular condyle and end of cardo (*h*, Pl. II, Fig. 19), and by a triangular region extending posteriorly and laterally from hypostoma as far back as the posterior margin of the tentorial bridge (Pl. II, Fig. 19). It supports the clypeus and the mandible, is adjacent to the exterior part of the maxilla, and surrounds the antenna, separating the antennal basal skin from the mandibular connecting membrane (Pl. II, Fig. 21). Exposed parts of head capsule roughened by numerous granules and set with light fine hair all over the surface; a series of setæ present, reaching from antennal base obliquely upward and backward.

Foramen in middle of ventral surface of head capsule: Elongate oval, almost one-third as long as capsule; posteriorly and laterally limited by sharply infolded margins of epicranium, anteriorly by tentorial bridge (*tb*, Pl. II, Fig. 19).

Sutures: Distinct frontal sutures obliterated. Epicranial suture concealed by prothorax when head is in natural position, three times as long as width of clypeus; anterior two-thirds of suture (*es*, Pl. II, Fig. 17) dorsal, posterior one-third (*es*, Pl. II, Fig. 19) ventral, situated on recurved hind part of cranium.

Clypeus (Pl. II, Fig. 28): Oval, transverse; one-third as wide as cranial capsule, one-third as long as wide, slightly chitinized on each side of median oval part which is pure white; posterior margin of chitinized parts densely set with fine, light setæ about as long as length of clypeus.

Labrum (Pl. II, Figs. 28, 31): Transverse, obovate, with each posterior corner invaginated forming a slender chitinous process; entire width of labrum to width of cranial capsule as 1: 4; length to width about as 1: 3; slightly chitinized; disk divided by two parallel, longitudinal, straight bands into three divisions; median division somewhat larger than each lateral; entire anterior margin and the lateral divisions densely set with well developed, slightly pendent, brown setæ, about half as long as length of labrum.

Antenna (Pl. II, Fig. 28): About as long as length of clypeus, three-jointed, borne by large, conical basal skin. Basal joint cylindrical, about one-third the length of entire antenna; as wide as long. Second joint cylindrical, somewhat longer and narrower than basal joint. Apical joint conical, a little shorter than basal joint, half as wide as long. Corresponding to a supplementary joint, a small round spot ventrally near foot of apical joint. Basal joint anteriorly with a few short setæ; apical joint with single minute seta at the tip and a minute seta at the base.

Mandibles (Pl. II, Figs. 23–26): Strong, short, about one-fourth the length of cranial capsule; cuneate, with inner and outer surfaces subtetragonal, dorsal and ventral surfaces subtriangular; length, depth, and width almost equal. Inner surface apically with transverse cavity, about four times broader than long, anteriorly and laterally limited by sharp, thin, perlucid, slightly rounded edge, posteriorly gradually sloping down into median portion of inner surface. Median portion about twice as long as apical portion, transverse, subtrapezoidal, flat, longitudinally rugose. Posterior portion of inner surface transverse, about as long as apical and median together; outline irregularly rounded, disk with a few large, low lobes and with a large, globular, chitinous protuberance on side of the interior wall (Pl. II, Fig. 24, showing a longitudinal section of inner wall of mandible). Margin below posterior portion thick, heavily chitinized; projecting into the mandibular internal cavity; carrying a little trapeze-like process. Exterior, dorsal, and ventral mandibular surfaces smooth and shiny. Fossa and condyle large. Color of mandible black, base reddish brown; no setæ.

Maxilla (Pl. II, Figs. 27, 29): Outer lobe of mala (galea?) cushionlike, with round outline and somewhat flattened, about twice as large as palpiger (*pg*); dorsally (Pl. II, Fig. 20) and ventrally hairy, with several large setæ. Inner lobe (lacinia?) ventrally enforced and almost completely represented by a slender chitinization, twice as long as outer lobe and almost as long as stipes, anteriorly not reaching far beyond base of outer lobe, posteriorly reaching chitinization along inner margin of stipes; anterior half of chitinization of inner lobe stylus shaped; posterior half heavier and C-shaped. Stipes fleshy and about as large as the lobes and palpiger together; along inner margin with thin, light chitinous band which is broadest and strongest posteriorly where cardo hinges; fine, long setæ from antero-external surface. Maxillary palp slightly projecting beyond exterior maxillary lobe; two-jointed, borne by large, jointlike palpiger. Palpiger somewhat smaller than outer lobe; at base with chitinous setose half ring; at top on ventral surface with transverse series of setæ. Palpus as long as palpiger and about half as long as antenna; basal joint almost as long as thick, with a few minute setæ; apical joint as long, half as thick as basal joint, with small tactile papillæ on top (compare Pl. I, Fig. 5). Cardo (c. Pl. II, Fig. 27) rhomboidal, flat, chitinized; vertically placed against ventral surface of stipes; when at rest, concealed (Pl. II, Figs. 19 and 29).

Maxillary articulating area (*ma*, Pl. II, Figs. 29 and 19): Fleshy, almost as large as mala, connecting stipes and submentum.

Submentum (*sm*, Pl. II, Fig. 29): About as long as stipes; transverse, parabolic, twice as wide as long (Pl. II, Fig. 19), fleshy.

Mentum (*m*, Pl. II, Figs. 29 and 19): As long as submentum, not much wider than long; free, fleshy.

Stipes labii (*stl*, Pl. II, Fig. 29): Transverse, elongate, oval; length to width as 1:4; width to width of mentum as 4:5. Separated from mentum by a

chitinous, posteriorly convex band. No distinct palpiger labii. Palpus labii with two joints, proportioned as those of the maxillary palpus, but only two-thirds as long and wide as these.

Ligula (*li*, Pl. II, Figs. 29 and 20): Triangular, as long as stipes labii, as wide as long. Ventral surface fleshy, setose. Dorsal (buccal) surface finely papillose; both ventral and dorsal surfaces simple, unpaired.

Maxillular area (=paraglossa=paragnatha auctorum) (*mxl*, Pl. II, Fig. 20): Paired, elongate, membranous, slightly lobate, near median line with a longitudinal series of densely set, short setæ. Between the two maxillular areas, a narrow, slightly chitinized, longitudinal groove.

Hypopharynx (*hyp*, Pl. II, Fig. 20): Membranous, nude, without chitinization on the upper surface. On the underside of the skin with unpaired, elongate, sling-shaped, anteriorly somewhat narrower thickening; possibly corresponding to a pair of transversely connected hypopharyngeal rods.

Epipharynx (Pl. II, Fig. 31): Membranous, anteriorly and laterally with medium long setæ; median disk nude. Epipharyngeal rods (*er*) well developed.

Legs (Pl. I, Fig. 16; Pl. II, Fig. 30): Three pairs; each pair widely separated by intermediate sternal region; all four-jointed, well developed, not fully of medium size; total length and length of individual joints almost the same for all pairs and equal to the height of head; anterior pair somewhat stronger and thicker than the two posterior ones. All legs whitish with strongly chitinized, dark brown, claw-shaped tarsus. Coxa conical, projecting, with base twice as wide as top; length equal to diameter of base and about one-fifth of the length of the entire leg; ventrally with long setæ. Trochanter not distinct. Femur subcylindrical, laterally somewhat flattened; twice as long as coxa, twice as long as thick; ventrally and laterally with numerous long, soft hairs. Tibia of front leg (Pl. II, Fig. 30) obovate, laterally somewhat flattened, bent at base; tibiæ of the other legs cylindrical and straight at base; length of front tibia in proportion to length of front femur as 2:3, lengths of the other tibiæ in proportion to the lengths of corresponding femora as 1:1; front tibia slightly narrower than front femur; the other tibiæ as thick as the corresponding femora. Long, dark brown hairs, densely scattered over the entire surface. A t bial spine present in front of claw-shaped tarsus; largest on prothoracic tibia. Claw-shaped tarsus inserted posteriorly on tip of tibia; curved with concavity forward.

Body form (Pl. I, Fig. 16): Curved, clavate, cylindrical, gradually thickening from middle of abdomen toward prothorax; prothorax approximately hemiglobular. Body about four times as long as the median abdominal segments are high; greatest height of thoracic segments one-half more than the height of the median abdominal segments. Epipleural lobes ventrally swollen and on the median body segments with numerous light brown hairs tuftlike or gathered together.

Body chitinizations and color[20]: Dull white to light yellow, no chitinous parts, except the oblique lateral prothoracic rod. Anterior and ventral end of this rod distinguished by a light brown spot in front of the thoracic spiracle, posterior and dorsal end marked as a dark brown line gradually tapering into the middle of the side of the segment; the intervening rest of the rod colorless. On the feeding larva the digestive tract shows through the tergites as a colored line which varies from cream to dark red according to the nature of its host. This line tapers posteriorly from the first abdominal tergite, recurving in hook shape on the lateral margins of the last two terga.

Body areas (Pl. I, Fig. 16): Cervical region with large presternal area; prothorax with only a single distinct dorsal area; mesothorax and metathorax with two dorsal areas (prescutum and the united scutum and scutellum); the first five abdominal segments with three dorsal areas (prescutum, scutum, scutellum); the sixth with two (prescutum and the united scutum and scutellum); the seventh to ninth segments with undivided dorsum. Seventh to ninth abdominal terga slightly hairy in a transverse belt along the posterior margins of the segments; terga of the other segments smooth and naked.

Ninth abdominal segment: Rounded, longer than eighth; without armament of any sort.

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[20] This paragraph on body chitinization and color is copied from notes containing good descriptions after living material with exact measurements of the different larval stages given the author by R. D. Hartman for free use in preparation of the present study. (A. G. B.)

Tenth abdominal segment: Much smaller than ninth, hardly one-fifth its size; truncate. Anal opening (Pl. I, Fig. 16) longitudinal; between two oval anal lobes.

Spiracles (Pl. II, Fig. 32): Nine; bilabiate, with slightly chitinized peritreme; elongate oval, more than three times as long as wide; longest diameter extending dorso-ventrally. Spiracular opening set all around with stiff, hairlike spines reaching half way to opening's longest diameter. First (mesothoracic) spiracle larger than the rest; located in the epipleurum of prothorax. Abdominal spiracles all of same size and all placed alike, near lower margin of terga.

Body movements:[21] Very active.

Remarks Referring to the Deviating Morphological Structures of the First-Stage Larva.

Pl. I, Figs. 1–7, 9–12.

Length of larva: Three-sevenths the length of the egg; same width as egg. Average length without spine, 0.76 millimeter; with spine, 0.83 millimeter; length of exposed part of head, 0.10 millimeter. Width of head, 0.17 millimeter; of prothorax, 0.36 millimeter; of the middle of body, 0.24 millimeter; of ninth abdominal segment, 0.10 millimeter.

Labrum (Pl. I, Fig. 3): Subtriangular, divided as in mature larva by two longitudinal, parallel bands into three divisions. Setæ straight, comparatively longer than in mature larva, fewer than in this.

Antenna (Pl. I, Figs. 2 and 4): Very short, consisting of a flat and ovate basal membrane carrying a single small joint (*a*) with a separate low basal ring (*b*) and a slightly smaller supplementary joint (*c*).

Mandible (Pl. I, Fig. 4): Apex formed by two flat, blunt, curved, anteriorly converging, toothlike thickenings of almost equal size and shape, one thickening dorsal (*a*), the other ventral (*b*), united by a thin chitinous wall (*c*), possibly corresponding to the thin wall of the anterior mandibular cavity in the mature larva. Biting surface (*d*) flat, disklike, with free, slightly projecting anterior and lateral margins. Color of entire mandible light brown.

Ventral mouthparts (Maxilla, labium, mentum, and submentum) (Pl. I, Figs. 4, 5, 6): All essential morphological features as in mature larva; the proportions of the different structures, however, somewhat deviating; the comparatively large size of ligula (*li*, Pl. I, Fig. 6) especially noticeable.

Legs (Pl. I, Figs. 10, 11, 12): Very reduced. First pair (I) with two indistinctly separated joints; about five setæ. Second pair (II) wart shaped; with two setæ. Third pair (III) almost absent, represented by minute conical elevation of the skin; with one small seta.

Body form (Pl. I, Fig. 1): Orthosomatic, clavate-cylindrical, tapering from prothorax; rates of height of thorax to height of an average abdominal segment as 4:3. Dorsally plicate, with plicæ arranged as in mature larva.

Body color, chitinizations, and setæ (Pl. I, Fig. 1): Shiny white, with granulated appearance. Soft; chitinous rod present on prothorax. No setæ.

Ninth abdominal segment (Pl. I, Fig. 7): Dorsally longer than eighth. Terminal half armed with chitinous and yellowish, unpaired, depressed, triangular tail spur, at end abruptly truncate and on each side posteriorly serrate; a few scattered setæ.

Tenth abdominal segment (Pl. I, Fig. 1): Completely covered by armed ninth. Anal opening, a longitudinal slit.

Body movements: Sluggish.

The most striking characters of the first-stage larva are the orthosomatic body shape, the apparently apically bilobed mandible, the rudimentary legs, and the tail spur on the ninth abdominal segment.

According to recent observations by Dr. T. E. Snyder on the different stages of *Lyctus planicollis* Lec., corresponding characters are found in the first-stage larva of this genus, namely, a straight, orthosomatic body as compared with the curved cyrtosomatic body of the other stages, rudimentary legs as compared with the well developed legs of the other stages, and, instead of an unpaired tail spur as in *Scobicia*, a pair of short, conical, slightly upward curved, pointed

[21] For further information on the habits of the different larval stages see pages 15–16.

cerci on the dorsal side of the ninth abdominal segment; the other larval stages of *Lyctus planicollis* Lec. being without armature. (Pl. I, Fig. 8 sketched by Dr. Snyder from a larva in balsam mount reared from the egg; showing ninth abdominal segment from the end, placed in somewhat oblique position to exhibit both of the cerci and at the same time give a view of their lateral outline.)

Second and Following Larval Stages.

Pl. I, Figs. 13, 14, 15.

In the general aspect and the shape and proportions of the morphological details, the second larval stage is only slightly different from the mature larva, which may be seen by a mere comparison of Pl. I, Figs. 13–15 with the corresponding figures of the mature form. The following stages also are almost identical with the mature larva, except in size and minor details.

SECOND LARVAL STAGE.

Length: 0.56 millimeter; width, 0.21 millimeter; length in proportion to length of first stage larva (Pl. I, Fig. 9 drawn with same magnification as Pl. I, Fig. 13) as 3:4; width as 4:3.

Head capsule: With few setæ.

Labrum: Not densely set with setæ.

Mandible: Brown.

Maxillary outer lobe and ligula: Not densely covered with setæ.

Legs: First pair with five setæ. Second pair with three. Third pair with two setæ.

Body form, color, and setæ: Slightly curved. Epipleural lobes not developed. Dull white. Few setæ dorsally on the posterior abdominal segments.

Body movements: Active.

THIRD LARVAL STAGE.

Head capsule: With more setæ than in preceding stage.

Labrum: Distally covered with numerous light brown setæ.

Mandibles: Dark brown.

Maxillary outer lobe and ligula: Covered with numerous setæ.

Legs: First pair with 7 setæ on femur; 8 to 10 on distal end of tibia; tibial spine developing near claw-shaped tarsus. Second pair with 1 seta on femur; 5 on tibia; tibial spine developing. Third pair with no setæ on femur; 4 on tibia; tibial spine developing.

Body form, color, and setæ: Curved. Epipleural lobe developing. Dull white. Posterior abdominal segments more hairy than in preceding stage; epipleural lobe with a few setæ.

Body movements: Active.

THE FOURTH AND FOLLOWING LARVAL STAGES.

These stages differ from the third stage by darkening of mandibles and chitinization on ventral mouthparts; by presence of more and coarser setæ on femora and tibiæ; by stronger development of tibial spines; by more curved form; by a stronger coloring of chitinous rod of prothorax; by more prominent epipleural lobes with additional setæ. Body movements are very active.

Body proportions of a medium sized larva: Length, 5 millimeters; width, 1.75 millimeters; distance between head and anus when curled, 3.50 millimeters.

Prepupal larva: Length, 8 millimeters; width, 2.75 millimeters. Creamy white or light yellow. Straightened and more active.

DESCRIPTION OF THE MATURE ADULT OF SCOBICIA DECLIVIS LEC.

By R. D. Hartman.

GENERAL DESCRIPTION.

Form cylindrical, head deflexed; size small (average length, 5.85 millimeters; average width, 2.10 millimeters); the prothorax and abdominal sternites about

equal in length. Color dark brown to black, mostly black; antennae, mouthparts (except mandibles), femora, and tarsi light amber; tibiæ, posterior lateral area of prothorax, and tumid area on the anterior lateral portion of elytra dark amber.

DETAILED DESCRIPTION.

Head: Rugose, globular, deeply evaginated into prothorax, tapering caudad and cephalad from its center. Eyes convex, prominent, elevated from head caudad, possibly for reception of prothoracic margin when head is strongly reflexed. Antennæ inserted in front of eyes, 9-jointed, with a 3-jointed club, last joint oblong, appearing slightly longer than joints 7 or 8, joint 7 broadest and prominently flanged, intermediate joints 3, 4, 5, and 6 shorter than joints 1 and 2 combined. Gula distinctly outlined. Clypeus indistinct. Labrum wedge-shaped, broader than long, distal margin covered with heavy tuft of light brown hairs. Mentum and submentum divided by distinct suture, of same width at suture, the former longer than broad, tapering toward ligula; latter broader than long, tapering toward gula; submentum heavily chitinized. Maxillary palpi 4-jointed, basal shortest, distal longest. Galea and lacinia prominent, hairy. Labial palpi 3-jointed; basal short, confluent; distal elongate, tapering from its base. Mandibles simple, moderately pointed, gradually widening dorsally and bearing on the inner margin toward the base a small molar tooth. Beginning at the base of each mandible a semicircle of dark brown hairs extending very prominently over the front.

Prothorax: Pronotum as broad as long, cephalic margin smooth and truncate, caudal slightly flanged and circular, anterior lateral area bearing a number of strong rasplike tubercules, these diminishing in size dorso-posteriorly; posterior lateral area smooth, shiny, and testaceous. Prosternum occupied mostly by coxal cavities; much broader than long, giving the prothorax a hood-like shape. No marginal lines.

Mesothorax: On the mesonotum the prescutum is a triangular sclerite with the scutellum plainly exposed. Mesosternum also triangular, but reversed from prescutum; the poststernellar piece separates the coxæ while the cephalic aspect of the sternum nearly reaches the prosternal margin but is prevented by the episternal sclerites joining at this point; these large sclerites bear numerous indistinct, irregular punctures. The episternum and prescutum are separated by the subcostal head.

Elytra: Entire, striæ irregular, punctures larger dorso-posteriorly; two rather inconspicuous costæ on each elytron anteriorly, the dorsal costa gradually joining the sutural margin which forms an acute tooth near the apex of the obliquely truncate declivity. Sutural striæ deeply impressed posteriorly but not entering the declivity. Declivity smooth and shiny between the prominent sutures, bearing very small light brown hairs. Lateral margin gradually undate near the middle, a tumid area on each elytral shoulder, color dark amber; balance of elytra piceous.

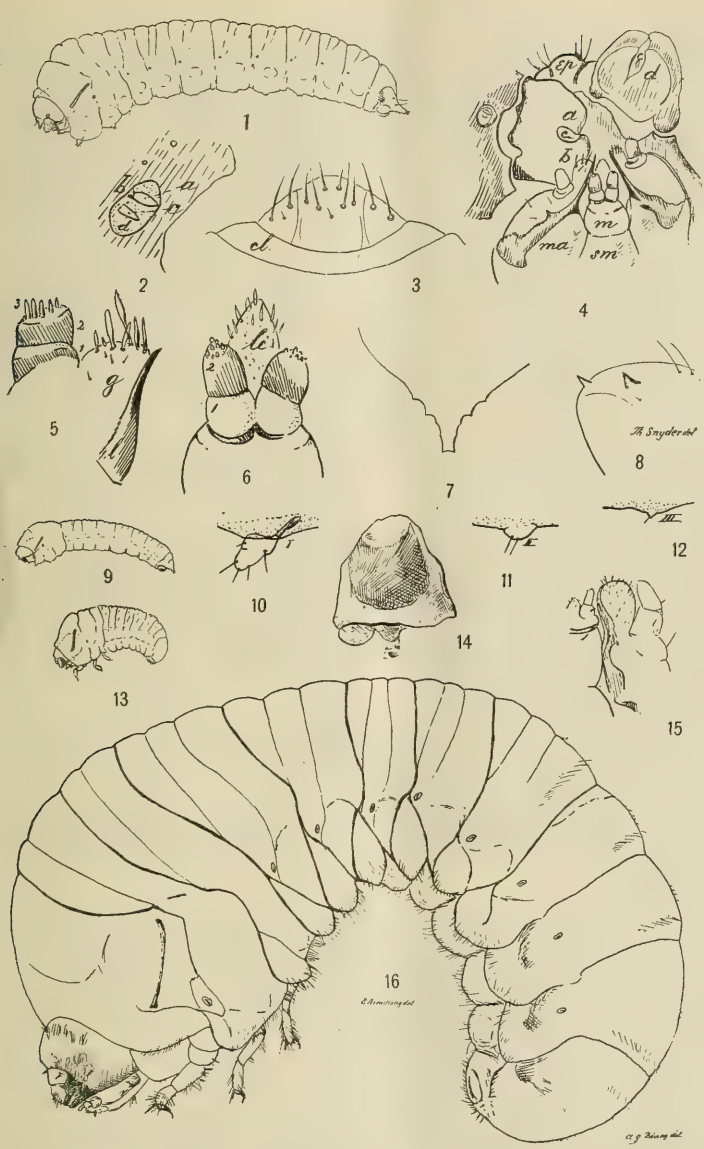
Metathorax: Metatergal groove distinct, arrow-shaped; scutellum prominent; postscutellum with a median emargination partially covered by the first abdominal tergite. Metasternum longer than either the prosternum or mesosternum, no distinct median line; sternal and episternal sutures clearly outlined, episternum elongate. The sternellar piece is divided for the reception of the intercoxal process. (The sternellar area and third abdominal sternite are grooved for the reception of the hind femur.)

The metathoracic wings are rather interesting in their length, venation, and the method by which their apex is folded when at rest. The subcosta soon parallels the costa, making a wide dark chitinized outer margin, while the radius dips well into the center and one branch joins the costa and subcosta at about two-thirds the length of the wing (this being nearly the length of the elytra), the veins showing a heavy elevated chitinization at their junction and forming a large closed cell that corresponds with the ventral aspect of the elytron, the other two branches of the radius joining the anal angle to strengthen the wing; the area toward the apex bears two veinless chitinizations which seem to act as weights that assist in properly folding the wings when not in flight.

Legs: Coxæ of anterior and middle pair globular; posterior coxa with a long, tapering, transverse sclerite terminating near the episternal suture; anterior pair contiguous, middle pair separated by the sternellum, and posterior pair by the intercoxal process. Trochanters small, without trochantins. Femora slightly swollen, pale testaceous, grooved at the distal inner margin for the reception of the tibia. Tibiæ slender, about same length as femora, dark amber,

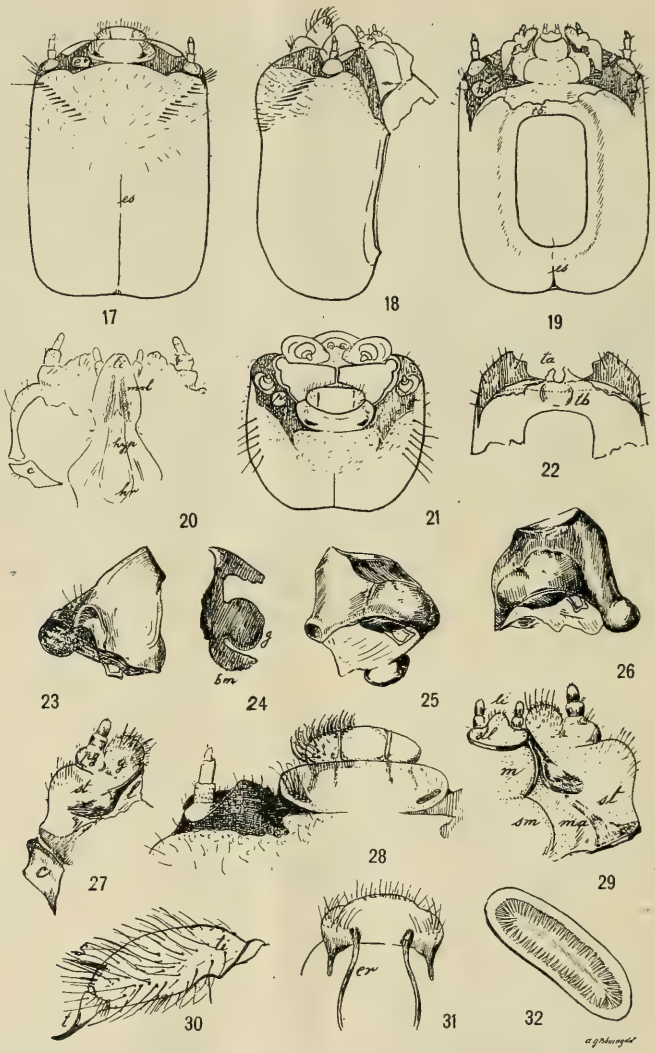
external margin serrate; anterior pair terminating in a hooklike spur, the middle and posterior pairs differing in having two tibial spurs. Tarsi 5-jointed, first joint very short, last longest, distal end bearing simple claws.

Abdomen: Tergites eight, first longest, anal or pygidium nearly quadrate, intermediate about equal in length. Spiracles seven, first much the largest. Sternites eight, 1 and 2 hidden by the sternellar area, 3, 4, 5, 6, and 7 plainly visible and sparsely covered with fine light hairs, 3, 4, 5, and 6 varying but little in length, 3 being largest, 7 and 8 differing as to sex. In the male the seventh sternite has distinct pleural pieces, anal end truncate, while in the female these pieces are less distinct, anal end emarginate; this latter character is hard to detect in living active specimens, being somewhat obstructed by the thick pubescence. The eighth or anal sternite in both sexes is retracted into the abdomen. In the male this sternite has two loosely connected chitinized shields covering the oedagus and anus; just dorsad of this shield another sclerite gives further protection to the oedagus, in the form of a transparent sheath (outlined with rather strong decurved chitinized margins that are recurved and divided at apex) just ventrad of the oedagus, which is slender and obtusely pointed. Length of vasa deferentes, 0.23 millimeter; length of oedagus, 0.34 millimeter. In the female this sternite is firm and more compact. It includes both the anus and the ovipostor. The anus bears a separate shield that is flanged ventrally through which the ovipositor is guided. The oviposter is long, about 2.37 millimeters, slender and flat with the exception of the apex which is slightly enlarged, subcylindrical, and bears a few rather rigid irregular setæ; the apex consists of about 0.27 millimeter of the ovipositor, including the 0.04 millimeter palpi at the terminal. Between the palpi the terminal is bilobed.



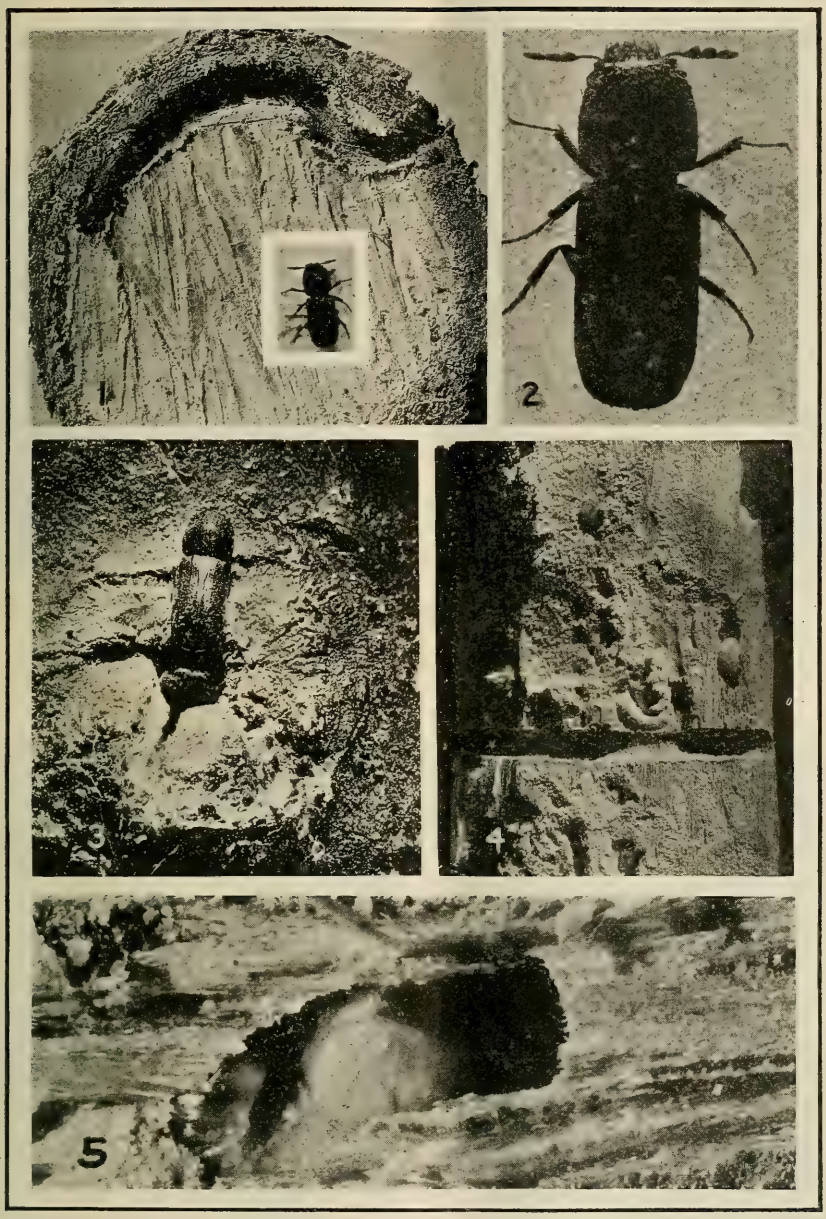
THE LEAD-CABLE BORER (SCOBICIA DECLIVIS).

FIGS. 1–7 and 9–12.—First-stage larva. FIGS. 13–15.—Second-stage larva. FIG. 16.—Mature larva. FIG. 8.—First-stage larva of *Lyctus* sp.: Posterior end of ninth abdominal segment with two cerci, oblique view from behind. FIG. 1.—Lateral view. Natural length, 0.75 millimeter. FIG. 2.—Antenna: *a*, Antennal joint; *b*, basal ring; *c*, supplementary joint; *d*, basal membrane. FIG. 3.—Labrum and clypeus, dorsal view: *cl*, Clypeus. FIG. 4.—Antenna, epipharynx, and mouthparts: *a*, Dorsal toothlike thickening of mandible; *b*, ventral toothlike thickening of same; *c*, thin chitinous wall between *a* and *b*; *d*, flat inner surface; *ep*, epipharynx; *m*, mentum; *ma*, maxillary articulating area; *sm*, submentum. FIG. 5.—Maxilla: *l*, Inner lobe represented by stylus-like chitinization; *g*, outer lobe; *1*, basal joint of maxillary palp; *2*, apical joint of same; *3*, tactile papillæ. FIG. 6.—Labium: *li*, Ventral side of ligula; *1*, basal joint of labial palp; *2*, apical joint of same. FIG. 7.—Tail spur, outline seen from below. FIG. 9.—Lateral view. Natural length, 0.75 millimeter. FIG. 10.—Skin with prothoracic leg (I). FIG. 11.—Skin with mesothoracic leg (II). FIG. 12.—Skin with metathoracic leg (III). FIG. 13.—Lateral view. Natural length, 0.56 millimeter. Drawn with same magnification as Figure 9. FIG. 14.—Right mandible, showing its interior or biting surface. FIG. 15.—Ventral mouthparts: Details of ventral surface. FIG. 16.—Lateral view. Natural length, 10 millimeters. All figures drawn by Adam G. Böving, except Figure 8, which is by T. E. Snyder, and Figure 16, which is by Miss E. Armstrong.



THE LEAD-CABLE BORER (SCOBICIA DECLIVIS).

Morphological details of mature larva. FIG. 17.—Dorsal surface of head: *e*, Epistoma; *es*, epicranial suture, dorsal part. FIG. 18.—Lateral surface of head. FIG. 19.—Ventral surface of head: *es*, Epicranial suture, ventral part; *h*, hypostoma (see arrow; letter *h* placed in triangular continuation of hypostoma); *tb*, tentorial bridge, partly overlapped by presternal part of cervical membrane. FIG. 20.—Dorsal surface of maxillæ, ligula, maxillulæ, and hypopharynx: *hyp*, Hypopharynx; *li*, buccal side of ligula; *mxl*, maxillular area with longitudinal series of short setæ; *hyp*, hypopharynx with sling-shaped chitinization (*hr*) shining through surface. FIG. 21.—Anterior surface of head: *p*, Pleurostoma. FIG. 22.—Tentorium, ventral surface: *ta*, Tentorial arm; *tb*, tentorial bridge. FIG. 23.—Dorsal surface of left mandible. FIG. 24.—Longitudinal section of inner wall of mandible: *bm*, Thickening of basal margin; *g*, globular enforcement of posterior portion of wall. FIG. 25.—Left mandible, showing base with marginal thickening which carries trapeze-shaped chitinization; dorsal wall with fossa mandibularis; inner wall with anterior cavity, posterior thickening, and intermediate portion. FIG. 26.—Left mandible: Inner or buccal surface. FIG. 27.—Ventral surface of right maxilla: *c*, Cardo, showing its entire surface; *g*, outer lobe of mala (galea?); *l*, inner lobe of mala (lacinia), showing the small membranous part and the stylus-like chitinization; *pg*, palpiger; *st*, stipes. FIG. 28.—Antenna, clypeus, and labrum, dorsal surface. FIG. 29.—Ventral mouthparts, ventral surface: *li*, Ligula; *m*, mentum; *ma*, maxillary articulating membrane; *sm*, submentum; *st*, stipes of left maxilla; *stl*, stipes labii. FIG. 30.—Exterior surface of distal end of left prothoracic leg: *s*, Spine; *t*, claw-shaped tarsus; *ti*, tibia. FIG. 31.—Epipharynx: *er*, Epipharyngeal rod. FIG. 32.—Prothoracic spiracle. All figures, greatly enlarged, drawn by Adam G. Böving.



THE LEAD-CABLE BORER.

FIG. 1.—Female beetle in typical egg or parent gallery of host tree. Note a slight return toward the surface after entrance is secured. Enlarged about twice. Insert, beetle, enlarged about twice. FIG. 2.—Dorsal view of beetle, enlarged 8½ times, showing rugosities on prothorax, and tibial spurs. FIG. 3.—Pair of beetles mating at entrance of egg gallery. Note elytral tip of female, just visible. The normal time for copulation seems to be shortly after the female has constructed her entrance gallery. Enlarged about 3½ times. FIG. 4.—View of portion of parent or egg gallery, showing larval mines and a few larvæ on either side. These larvæ are probably from another egg gallery or returning toward their own gallery. Enlarged about 1¾ times. FIG. 5.—Lateral view of larva in mine of host tree. Note the distance left clear between larva and blind end of mine, this space being used by the larva in reversing; also dark area on chitinized line of prothorax. Enlarged about 10½ times. Photographs by R. D. Hartman.

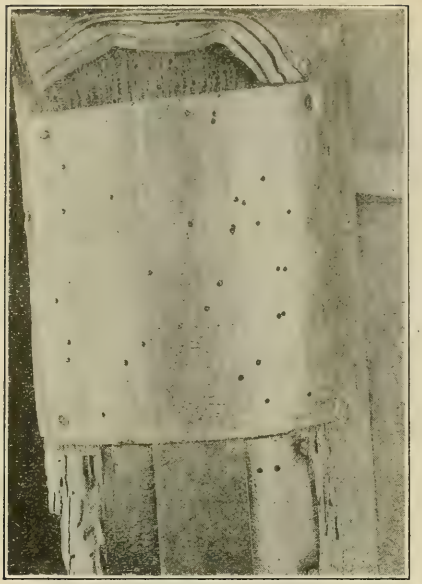


FIG. 1.—Infested section of oak covered with alloys and building paper in layers, but with narrow strip of sheet steel that was placed between layers of lead alloy and top layer of alloy removed. Shows beetles in holes where they were stopped by steel. Photograph by H. E. Burke.

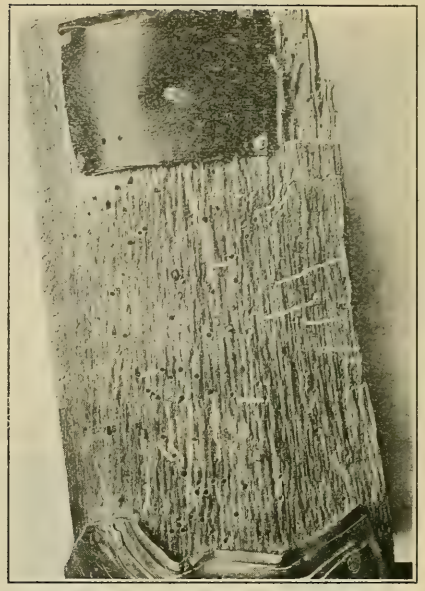


FIG. 2.—Section of infested oak with all the layers of alloy removed, showing how many of the beetles attempted to escape from the sides instead of boring through the alloys. Photograph by H. E. Burke.

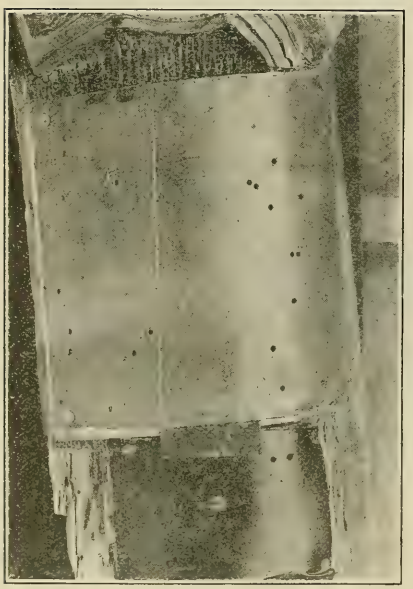


FIG. 3.—Infested section of oak covered with alloys and building paper in layers. Beetles have emerged through all except where narrow strip of sheet steel was placed between layers of lead alloy. Photograph by H. E. Burke.

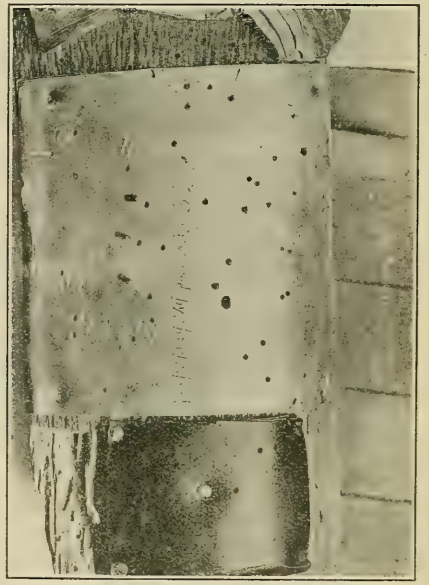


FIG. 4.—Same as Figure 1, except that next layer of alloy has been removed. The larger hole was made by the round-head borer *Xylotrechus nauticus*. Photograph by H. E. Burke.

THE LEAD-CABLE BORER.

FIG. 1.—Sheet of lead alloy which was tacked over infested section of oak. Area between the lines marked *A* was covered with a strip of zinc which prevented the beetles from emerging. (Table 1, No. 26b.) Photograph by H. E. Burke.

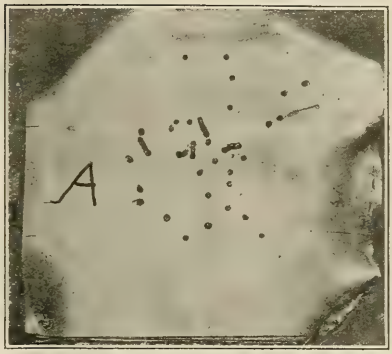


FIG. 2.—Sheet of lead alloy just under the preceding. Shows how the beetles mined to the side when they were stopped by the zinc. (Table 1, No. 26b,) Photograph by H. E. Burke.

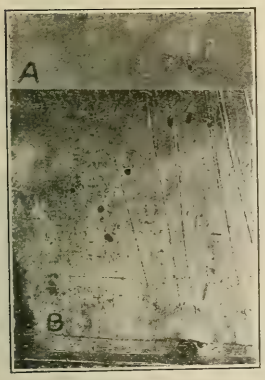


FIG. 3.—*A*, sheet of lead alloy which was covered by the sheet of zinc, *B*. Most of the beetles were unable to penetrate the zinc and stopped in *A*. One, marked *A* on sheet *B*, did penetrate the zinc. (Table 1, No. 25b.) Photograph by H. E. Burke.

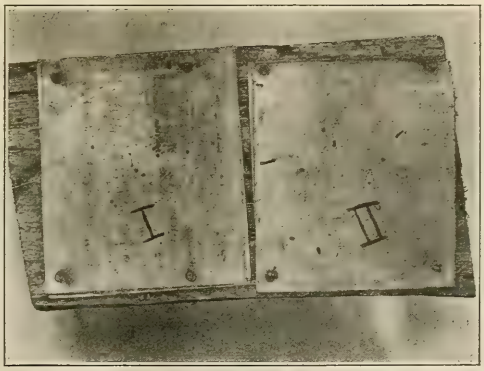


FIG. 4.—Sheets of lead alloys tacked over infested wood. *I* was covered with a sheet of lead carborundum coated on the upper or outer side. It did not seem to stop the beetles at all. Note clean-cut holes. *II* was covered with a sheet of lead carborundum coated on the inner side next to it. It seemed to stop most of the beetles. Note how they mined to the side in attempting to escape boring through it. (Table 1, Nos. 2a, 2b.) Photograph by H. E. Burke.

THE LEAD-CABLE BORER.

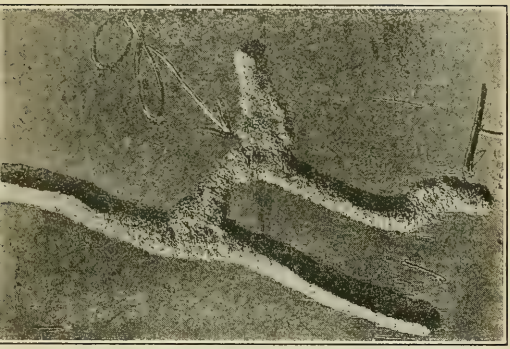


FIG. 1.—Section of lead showing the branched minings and mandibular impressions of two beetles. This was the underside of the second layer of lead, which was rolled unevenly and permitted the light to penetrate; thus the minings were irregular. Enlarged 1¾ times. (Table 2, No. 4.) Photograph by R. D. Hartman.

FIG. 2.—First layer of tin-coated lead *down* after bein removed from infested section, showing 58 attempt of which 24 were successful, in penetrating at lea the first thickness. In many cases where the beetl attempted to escape between the section and th lead, they mined more in the lead than those tha penetrated several thicknesses. One-fourth natur size. (Table 2, No. 52.) Photograph by R. I Hartman.

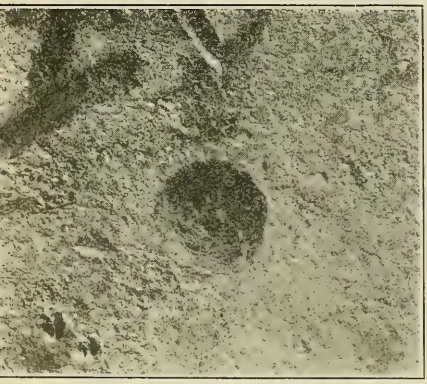


FIG. 3.—Typical beetle mine or single exit burrow in lead sheathing, enlarged 6½ times. Beetle had mined about two-thirds through the sheathing. Photograph by R. D. Hartman.

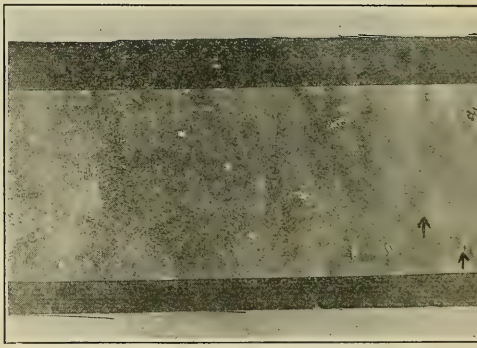


FIG. 4.—First layer of sheet zinc after being removed fr infested section, showing 31 attempts, of which 2 we successful, in penetrating one thickness. These are des nated by arrows. Three-tenths natural size. (Table Photograph by R. D. Hartman.

THE LEAD-CABLE BORER.

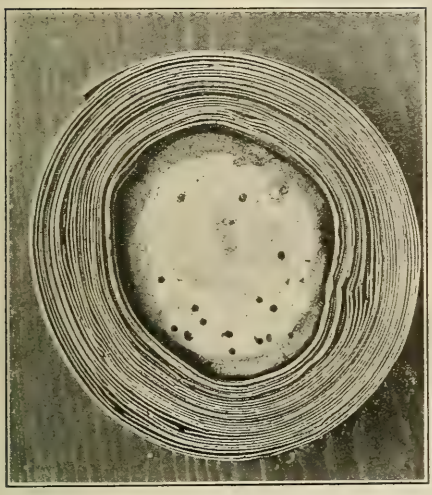


FIG. 1.—Method of wrapping infested oak with lead sheathing to determine number of thicknesses beetles are able to penetrate in emerging. Larval mines in wood and emergence holes of beetles in end of section. (Table 2, No. 55a.) Photograph by H. E. Burke.

FIG. 2.—Infested section of oak wrapped with lead alloy to determine number of thicknesses o flead penetrated by beetles in emergence. Method of wrapping also shown. (Table 3, No. 62.) Photograph by H. E Burke.

FIG. 3.—Work of beetle and larvæ in infested section of live oak. Larval mines and egg galleries. Longitudinal section. Photograph by H. E. Burke.

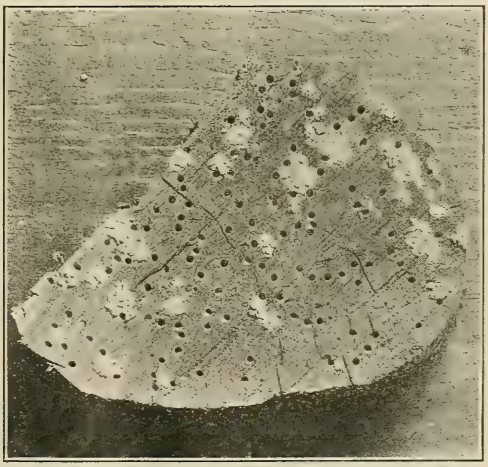


FIG. 4.—Cross section of infested oak, showing how the beetles sometimes emerge at the end of a section. Piles of dust indicate the work of the associated larvæ of the powder-post beetle *Lyctus planicollis*. Photograph by H. E. Burke.

THE LEAD-CABLE BORER.

FIG. 1.—Two sections showing exit holes through varnished and painted areas. *A*=varnished section, to two-thirds of which was applied, at intervals before emergence, 5 coats of spar varnish. Forty-six beetles emerged through varnished area and 11 in unvarnished portion. *B*=white-paint enamel section, to three-fourths of which was applied one good coat of this paint. Thirty-seven beetles emerged through the painted area and 18 through the unpainted portion. These experiments, as in most cases, gave no material check to the beetles' emergence. One-half natural size. (Table 4, Nos. 5 and 12.) Photograph by R. D. Hartman.

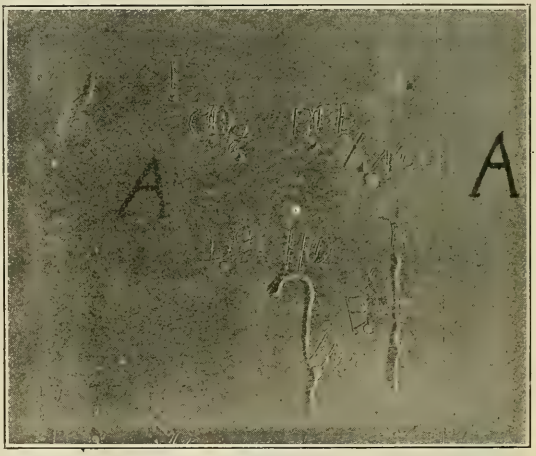


FIG. 2.—First thickness of lead sheathing after being removed from infested section. Previous to the lead being wrapped around the section about one-half of underside (*A*) was given 5 coats of spar varnish and 3 coats on infested section. Besides these numerous coats of varnish some beetles were able to penetrate 5 thicknesses of No. 3 lead and emerge. Two-fifths natural size. (Table 3, No. 56.) Photograph by R. D. Hartman

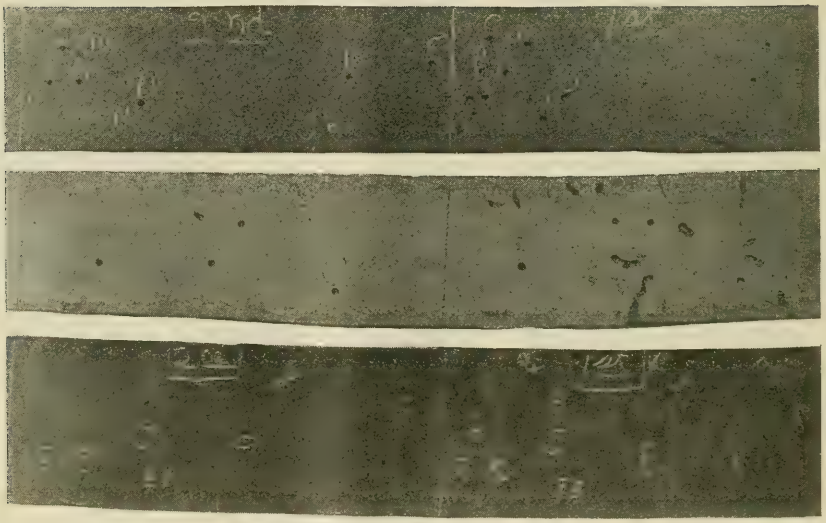


FIG. 3.—First two thicknesses of the three treated lead sheathings after being removed from infested section and manner in which beetles stopped as successive thicknesses were reached. Upper, embedded carborundum, where 17 beetles started in first thickness and 14 reached the second. Middle, tin-coated section, where 14 started in the first and 6 reached the second thickness. Lower, copper-coated section, with 16 and 12 penetrations, respectively. One-fifth natural size. (Table 2, Nos. 54, 54c, 54b.) Photograph by R. D. Hartman.

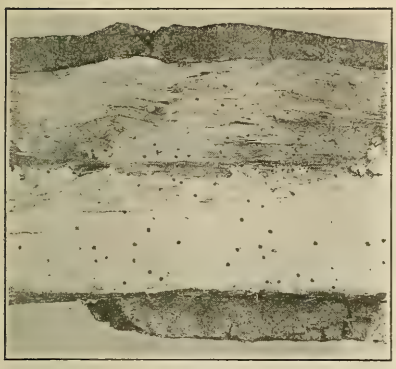


FIG. 1.—Section of infested oak with half of surface coated with tallow one-fourth inch thick. The beetle emerged through it without trouble as long as it was cold and hard. (Table 4, No. 8.) Photograph by H. E. Burke.

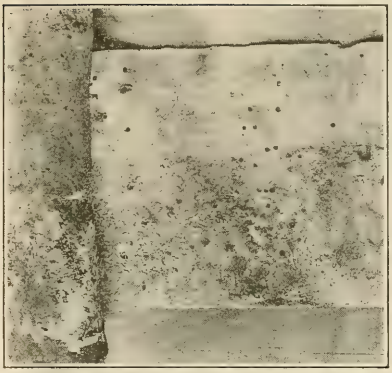


FIG. 2.—Part of roll of alloy, one-half of which was covered with tallow before it was rolled around infested wood. Holes are clean in untallowed section. A number of beetles were caught and died in the tallow when it was softened by the heat. (Table 3, No. 11.) Photograph by H. E. Burke.

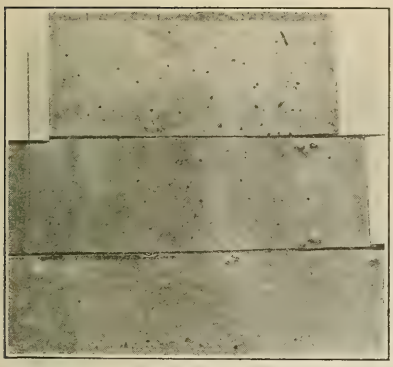


FIG 3.—Layers No. 1, No. 2, and No. 23 of lead alloy rolled 27 times around an infested section of oak. Shows how the numbers of beetles penetrating the alloy kept diminishing as thicknesses increased. Thirty-seven went through the first, 14 through 12, and only 3 through 23 thicknesses; two of these went through the 24th but were stopped by the 25th. This was the greatest penetration obtained. (Table 2, No. 55a.) Photograph by H. E. Burke.

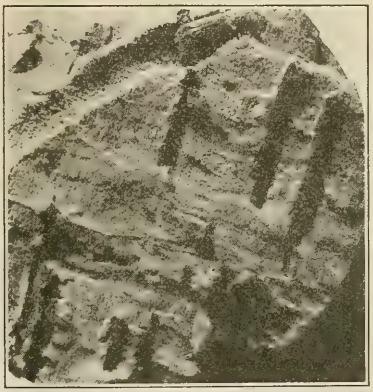


FIG. 4.—Beetle in gallery constructed in 30-mm. ($1\frac{1}{8}$-inch) cork. A num er of other beetles were found in similar situations, the corks being used as stoppers to vials containing specimen in alcohol. Enlarged $2\frac{1}{8}$ times. Photograph by H. E. Burke.

THE LEAD-CABLE BORER.

FIG. 1.—The upper cage incloses section of regular commercial cable and two suspension rings. The lower cage incloses section of dead cable used as a check. Insert, view showing repair of telephone cable made necessary by an attack of the lead-cable borer. Photograph by H. E. Burke and insert by R. D. Hartman.

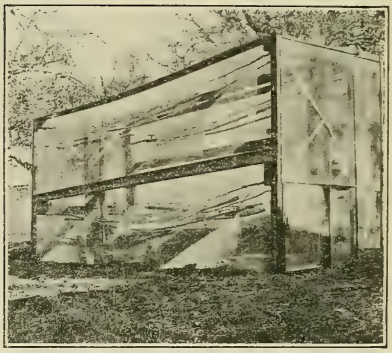


FIG. 2.—Test cables inside of cage, suspended by various types of rings. Some have direct current of electricity and some are without current; some were treated with various repellents and some were normal. Photograph by H. E. Burke.

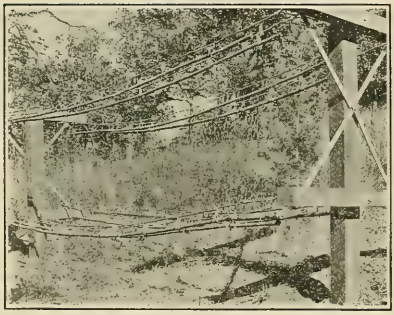


FIG. 3.—Cables on which cable tests were made. Photograph by H. E. Burke.

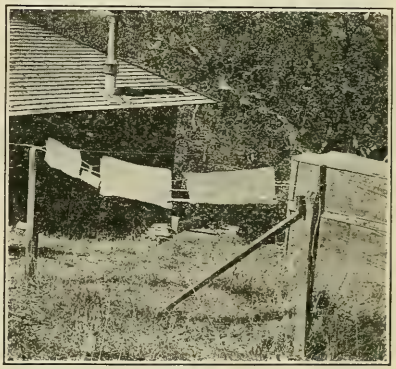


FIG. 4.—Section of cable and small cages built around it. These inclosed a section of the messenger strand, several suspension rings, and a section of the cable. Beetles were introduced into the cages to see if they would enter the cable. Photograph by H. E. Burke.

THE LEAD-CABLE BORER.

UNITED STATES DEPARTMENT OF AGRICULTURE

BULLETIN No. 1108

Washington, D. C. ▼ November 6, 1922

TABLES FOR THE MICROSCOPIC IDENTIFICATION OF INORGANIC SALTS.

By William H. Fry, *Scientist in Chemical Investigations, Bureau of Soils.*

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INTRODUCTION.

The identification of a salt by a qualitative chemical analysis necessarily presupposes the purity of the salt, since a qualitative analysis would make no distinction between an accidental impurity and a constitutional molecular group of the compound. But even with material of assured purity the results of the analysis would still be indefinite. Whether, for example, a substance containing K, H, and PO_4 was a monopotassium or dipotassium phosphate would be undecided. The whole question of hydrates would likewise be indeterminate. If the material qualitatively examined should be a mixture, the difficulties of identification would be insuperable by the analytical evidence alone.

If a quantitative analysis is made, the results would be sufficiently explicit in certain relatively simple cases if the material analyzed is known to be a single pure substance. But in other cases—for example, elemental sulphur—the analysis would give no evidence as to the particular allotropic form of sulphur—a point which in certain problems might be of considerable importance. Where the substance is a double salt, the analytical data would not differentiate between a double salt and a mixture of two simple salts; and the more complicated the molecular composition of the salt the more difficult would be the interpretation of the analysis. With mixed salts any calcu-

lation of the original composition of the materials from the analytical figures would be practically out of the question in all but a relatively few and simple cases.

Even where chemical analysis, either qualitative or quantitative, gives the desired information as to the existence of a certain compound, the time consumed in making the analysis is comparatively long. A method which would give reliable and rapid identifications is obviously desirable and for certain work imperative. For instance, a chemical analysis would readily give the percentage of the various elements in a mixed fertilizer, but further data as to the actual compounds of potash, say, which are present in the sample might be necessary for certain plot or pot experiments.

A number of methods designed to furnish evidence as to the constituents of mixtures have been proposed and used in certain limited fields of study. The separation of minerals in rock powders according to their specific gravities by means of solutions of appropriate densities was long in vogue, and even now is used occasionally. Ordinary microscopical observation of crystal forms has been used extensively, and, though sometimes abused, in the hands of an expert it can be made of considerable value. Its application, however, is limited to well developed crystals, and even then it furnishes only meager data of a definitive kind. The danger attending its use becomes apparent when one tries to identify one of the numerous "needle-shaped" crystals with no more data than can be obtained with the cross hairs and possibly the rotating stage of the microscope. Microchemistry at its best gives scarcely better results than a qualitative chemical analysis. The observation of absorption spectra with a microspectroscope is of extremely limited application. Up to the present time, petrographic methods are the best and apparently the only general solution of the problem.

PETROGRAPHIC METHODS.

The possible range of application of petrographic methods to chemical problems is almost unlimited. They have been successfully applied to the identification of compounds formed in concrete and cement mixtures and to general ceramic problems. It has been found possible to differentiate between phrenosin and kerosin derived from both the brain and the soil. The alkaloids and sugars afford notable instances of the rapid identification of substances without tedious chemical procedures.[1] Most phase rule work presents problems easily solved by the petrographic microscope. This application has already found commercial use in the study of brines. In the laboratory of the Bureau of Soils it has been shown to be feasible

[1] Wherry, E. T., U. S. Dept. Agr., Bul. 679 (1918).

to identify the various substances occurring in commercial fertilizers and the salts obtained from the evaporation of soil extracts. Other minor applications have been the examination of scouring soaps, products of dye manufacture, ground glass and sand in foodstuffs, incrustations and efflorescences on buildings, gas pipes, soils, etc., chemical precipitates, miscellaneous laboratory reagents, and commercial products such as ordinary salts and carborundum. Possibly one of the widest applications may be in the inspection of drugs and similar products.

The petrographic microscope was primarily designed for the identification of natural minerals. But since minerals are nothing more than a particular group of more or less definite and usually impure chemical compounds which occur in nature, the petrographic microscope is all the more applicable to the crystalline compounds of the laboratory where purity is usually of a fairly high degree. The methods have an immense advantage over ordinary microscopic observations of crystals in that particles showing crystalline forms or outlines are not essential. The petrographic determinations are made upon the optical constants with only incidental and occasional reference to crystallographic constants, and therefore can be made upon crushed or ground fragments showing no crystalline outlines almost as well as upon well-developed crystals. Furthermore, the optical methods are accurate and certain to a degree which can not be attained in a measurement of crystals under the microscope.

The optical properties have been repeatedly described and the methods for their determination given.[2] They are isotropy, or anisotropy, uniaxiality or biaxiality, optical character, refractive indices, birefringence, optic axial angles, dispersion, color, pleochroism, absorption, orientation, and such crystallographic properties as cleavage and system where possible. Isotropy, anisotropy, uniaxiality, biaxiality, and optical character are qualitative in their nature and serve simply to throw a particular substance into a classificatory group. All the other properties are specific for a given substance and serve to identify it when once placed in its proper group. Dispersion, color, pleochroism, and absorption are essentially qualitative as usually observed. Refractive indices, birefringence, optic axial angles, and orientation are distinctly quantitative, however, and refer to specific numerical values.

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[2] For an admirable and exhaustive account of methods see Johannsen, Manual of Petrographic Methods, New York, 1914. For a general critique of methods see Wright, The Methods of Petrographic-Microscopic Research, Their Relative Accuracy and Range of Application, Carnegie Institution of Washington, Pub. 158, 1911. An extremely elementary account of the simplest and most easily applied methods has been given by Fry, Identification of Commercial Fertilizer Materials, U. S. Dept. of Agr., Bul. 97, 1914. Among numerous other publications may be mentioned the classic works of Iddings, Rock Minerals, New York, 1906; Rosenbusch and Wulfing, Mikroskopische Physiographie der petrographisch wichtigen Mineralien, 1 Teil, Stuttgart, 1904; Schroeder van der Kolk, Kurze Anleitung zur Mikroskopischen Krystallbestimmung, Wiesbaden, 1898; and Larsen, U. S. Geol. Survey Bul. 679, 1921.

All of the optical properties named may usually be observed and measured where measurement is possible in about 15 minutes, with no more material than can be held upon the point of a knife blade, assuming of course that one has ready all the essential equipment for the work and is not under the time-consuming necessity of making a microscopical search for the material to be identified in a mass of other material. In certain cases, however, the time of search can be materially reduced or even eliminated. For instance, if one has a mixture of NaCl and KCl, the presence of either one but not both being known, the mass can be mounted in an oil of the same refractive index as that of the known substance, when the latter will be invisible or practically so and the unknown will stand out with a considerable degree of prominence, thus permitting ready "spotting" and a subsequent working down or up to its index with different oils. The value of this point in the rapid detection of impurities in supposedly pure substances is obvious.

EXPLANATION OF SYMBOLS.

For convenience in identification the substances have been tabulated in five groups as follows: Isotropic, uniaxial positive, uniaxial negative, biaxial positive, and biaxial negative substances. In the isotropic group the refractive index is the only property to be observed, and the arrangement of the substances is according to increasing values of the index. In the uniaxial positive and uniaxial negative groups there are two refractive indices to be measured, designated ω and ϵ, denoting respectively the ordinary and extraordinary rays of light as observed in polarized light. The difference between these two indices constitutes the birefringence of the substance. Other properties, such as pleochroism, are occasionally observable, and the crystal system should always be noted where possible. The arrangement of the substances is according to ascending values of the ω index.

In the biaxial positive and biaxial negative groups there are three refractive indices to be measured—that is, the α, β, and γ indices—indicating respectively the least, the intermediate, and the greatest index of the substances. The differences between any two of these are significant and are tabulated. The true optical angle is indicated by 2V. The symbols 2E and 2H indicate the value of this axial angle when measured in air and oil, respectively. Dispersion is tabulated as greater or less for red, ρ, than for violet, υ, light. In the columns headed "orientation," X, Y, and Z signify the directions of vibration of the α, β, and γ rays. Ax.pl. is an abbreviation for plane of the optic axes of the crystal. All the other symbols in this column are either geometrical or simple crystallographic designations of crys-

tal faces and axes. Pleochroism should be observed when present, and crystal system should always be identified where possible. The arrangement is according to ascending values of the β index.

OPTICAL PROPERTIES.

It can not be too strongly stated that geometrical and optical crystallography constitute two distinct classes of crystal investigations; closely interrelated, it is true, and mutually dependent for certain properties, but nevertheless far from being completely expressible in terms of each other. For example, a complete geometrical description of a crystal could do no more than indicate isotropy, uniaxiality or biaxiality, leaving all of the other optical properties completely undecided.

To show the relations between geometrical and optical crystallography and to explain briefly the optical terms and methods here used, the following résumé is given.

All crystals can be grouped into six major systems, each of which has numerous subdivisions or modifications. These major systems are the isometric, tetragonal, hexagonal, orthorhombic, monoclinic, and triclinic. Optically, these may be grouped into two classes, depending upon the mode of transmission of light in them in different directions. Substances belonging to the isometric system transmit light with equal speed, regardless of crystallographic directions. They therefore act very much as a piece of glass or other amorphous body. Such substances form the isotropic class. All belonging to the other systems transmit light with a speed which varies as the direction through the crystal varies. These form the anisotropic, doubly refracting, or birefringent class.

Anisotropic materials comprise two main groups, the first having only one optic axis, and the second having two. These are the uniaxial and biaxial groups, respectively. The uniaxial groups include the tetragonal and hexagonal systems, and the biaxial group the orthorhombic, monoclinic, and triclinic systems. The uniaxial and biaxial groups are further subdivided into optically positive and optically negative subgroups.

We therefore have an optical classification as follows:

Isotropic	Isometric system.		
Anisotropic	Uniaxial	Tetragonal, Hexagonal	Positive. Negative.
	Biaxial	Orthorhombic, Monoclinic, Triclinic	Positive. Negative.

Since light is not modified by the direction in which it traverses an amorphous or isometric substance, there is only one optical prop-

erty, aside from isotropy, which is to be determined; that is, the refractive index.

Since light, in passing through anisotropic media, is always doubly refracted, this group presents complications of refractive index and other determinable phenomena, all of which have diagnostic value.

Uniaxial crystals have two refractive indices, one of the rays vibrating parallel to the optic axis and another at right angles to this direction. Biaxial crystals have three indices, two lying in one plane and the third in another plane of the particle. Not only is each index of diagnostic value; but also the differences between the indices of a given substance, since these differences are a measure of the double refraction and therefore of the order of the interference colors shown between crossed nicols. Furthermore, the plus or minus value of the difference of the indices of rays vibrating in given directions determines the optically positive or optically negative character of the substance. If $\epsilon > \omega$ in a uniaxial substance, the substance is optically positive; if the reverse is true, negative. In biaxial substances, if $\beta - \alpha$ is decidedly greater than $\gamma - \beta$ the substance is optically negative, and if the reverse is true, positive.

Biaxial substances, suitably oriented, show the emergence of two optic axes, and the angle between these two axes is called the optic angle. Uniaxial materials may be considered as the limiting case of the biaxial group where the optic angle is zero.

Frequently red light is dispersed more or less than violet light, and this fact is of diagnostic value.

In any given substance other than amorphous or isometric there is always a specific relation between the directions of the optic axes or planes and the crystallographic axes, and therefore between the optic axes or planes and any given external face or line on the crystal. In other words, a given substance lying in a particular crystallographic position will always show the same value and orientation of its optical properties, whereas a change in the crystallographic position would usually change the orientation and might change the value of some given property—apparent refractive index, for example.

The absorption of certain colors of light in one optical direction in a crystal to a greater or less extent than in another direction gives rise to a change in color of the material depending upon the direction in which it is viewed. This is called pleochroism, and is characteristic of certain compounds.

The measurement of the refractive index is based on the principle that the contact between two substances of the same color and refractive index is invisible and the greater the difference between the indices of the two substances the more prominently one stands out from the other. If a substance is mounted in an oil of known refractive index, either the method of central or the method of in-

clined illumination may be used to determine whether the substance has an index higher or lower than that of the oil. This determined, the substance is mounted in another oil of appropriately higher or lower index, as the case may be, and the operation repeated. By this method of trial and error, an oil is found in which the given substance disappears. The refractive index of the substance is then the same as that of the oil. A little practice enables one to estimate quite closely the index of a substance observed in an oil of a definite but different index, and this estimation very materially reduces the number of trials that must be made before the correct oil is found.

The preceding description applies directly to the measurement of the refractive index of an isotropic substance. In the measurement of the indices of anisotropic substances, the problem is complicated by the fact that the index of the substance varies as the direction of the vibration of the light varies. With anisotropic substances, it is therefore necessary to ascertain carefully the optical orientation of all particles upon which the measurements are carried out. On a given substance in the proper orientation one index may be determined directly. A second index is in the same plane and consequently may be determined by a change in the orientation of the substance represented by simple rotation of the stage of the microscope. The third index must be measured upon the substance in another plane represented by a tilting of the grain. This tilting may be accomplished by a universal stage attachment on the microscope or by moving the cover glass, as, for example, with the point of a pencil. In the measurement of indices of anisotropic substances, regard to optical orientation is more often than not a considerable aid in identification.

Whether a given crystal is isotropic or anisotropic—that is, whether it is isometric or belongs to one of the other crystalline systems—is readily determined by crossing the nicol prisms of the microscope. Isotropic substances transmit no light under these conditions; whereas anisotropic substances, being doubly refractive, do transmit light and are readily visible. In making this test care must be taken that an anisotropic uniaxial substance is not so oriented that the line of vision is parallel to the optic axis of the substance and that no particles are observed only at their point of extinction. Tilting the grain and revolving the stage of the microscope will eliminate both of these possibilities of error. If the substance is known to be biaxial, simple revolution of the stage is sufficient.

Uniaxiality or biaxiality is established by converting the microscope into a conoscope by crossing the nicols and removing the ocular or by inserting the Bertrand lens and observing the interference figure of the particle in question. Uniaxial substances show a cross, if lying on a plane perpendicular to the optic axis. As the particle is tilted more and more out of this position the center of the cross finally is out

of the field of the microscope and only the arms of the cross are visible, each one coming into view separately and at right angles to the other as the stage of the microscope is revolved. In the limiting case where the particle is lying on a plane parallel to the optic axis the interference figure is practically indeterminate and the position of the grain must be altered.

Biaxial substances lying on a plane perpendicular to the acute bisectrix of the optic axes show the points of emergence of the two optic axes, which points mark the loci of two hyperbolæ, extending in opposite directions and momentarily coming together in the form of a cross as the stage is revolved. As the particle is tilted out of its perpendicular position one or other of the points of emergence first leaves the field of the microscope, only one hyperbola remaining in view. As the tilting continues this second point of emergence likewise leaves the field; but biaxiality is still evidenced by the curved portion of the hyperbola remaining in view. In the limiting case where the particle lies in a plane parallel to the plane of its optic axes, the interference figure is indeterminate and the position of the particle must be altered. In case there is a large acute angle between the two optic axes, both points of emergence are out of the field when the particle is in the perpendicular position. In such a case only one point of emergence can be observed at a time, and tilting is necessary.

If the interference cross of a uniaxial substance, or the interference figure, preferably revolved into the form of a cross, of a biaxial substance, be observed and a gypsum plate showing red of the first order be inserted, two opposite quadrants of the figures become blue in color and the other two opposite quadrants become yellow. The position of the quadrants colored blue and yellow establishes the optically negative or positive character of the substance under examination; but it is necessary to calibrate each microscope and gypsum plate as to the position of the colored quadrants. This can readily be done once for all by observation of a piece of muscovite. This mineral, being optically negative, gives the phenomena characteristic of negative substances. For positive substances the phenomena are simply reversed. In case the interference figures are highly colored, a quartz wedge may conveniently be used in place of the gypsum plate. But here, instead of noting the coloration of the quadrants, one must note the movement of the colored bands into or away from the center of the figure in the different quadrants as the wedge is slowly inserted. The bands in two opposite quadrants move in to the center and away from the center in the other quadrants. Here, as with the gypsum plate, the microscope must be first calibrated. Muscovite will serve very well for this purpose, a fairly thick piece showing the phenomena.

If the refractive indices have been determined with sufficient accuracy, the double refraction is simply their arithmetical difference. But it is sometimes desirable to determine the value experimentally. This can be done with the quartz wedge and an appropriate map of interference colors, such as is given in several of the textbooks referred to on page 3. For further details the references must be consulted.

Dispersion means simply that the axial angle is greater or less for red than for violet light. This may be determined by a measurement of the axial angles with lights of these two colors; but usually it is quite sufficient simply to observe the position of the colors in the interference figures. If both the hyperbolæ have the same dispersion, then a reddish color should be noted on the concave and a bluish color on the convex side of the hyperbola if $\rho < \nu$ and the reverse if $\rho > \nu$.

The orientation of a crystal is simply a statement of the relation of the optic directions and planes to the crystallographic axes and faces, and necessarily presupposes familiarity with and the possibility of identifying the crystallographic forms. This identification is not always possible with rounded or broken grains showing no crystalline outlines. In certain cases, however, the position of the crystallographic axes can be established by the optical data, and vice versa.

In compiling the tables an effort has been made to gather together all substances for which the optical constants are known with any degree of completeness and accuracy. It has been found necessary to eliminate a large amount of material for which the data are too meager to be of any real value. Especially was this so in the tables made by Bolland.[3] In many cases he failed to specify the particular hydrate of the salt he described or even note whether it was hydrous or anhydrous. It is hoped later on to take up these incomplete data in other publications treating of the differentiation of salts of known chemical groups. The main mass of data has been taken from Groth's "Chemische Krystallographie," (2 vols., Leipzig, 1906 and 1908), and from the pages of the Zeitschrift für Krystallographie und Mineralogie. Except for a very few common substances, all naturally occurring salts have been eliminated; for them reference should be made to the admirable tables of Larsen. Except where otherwise noted, all optical constants refer to measurements with the D line of the spectrum.

[3] Monatsh. für Chemie, 31:387-419 (1910).

TABLES.

TABLE 1.—*Isotropic Substances.*

Substance.	Refractive index n_D.
NaF [a]	1.336
$(NH_4)_2SiF_6$	1.3696
CaF_2	1.4339
$NaAl(SO_4)_2.12H_2O$	1.4388
$2Na_3PO_4.NaF.19H_2O$	1.4519
$NH_3(CH_3)Al(SO_4)_2.12H_2O$	1.4541
$KAl(SO_4)_2.12H_2O$	1.4562
$RbAl(SO_4)_2.12H_2O$	1.4566
$CsAl(SO_4)_2.12H_2O$	1.4587
63½ p. ct. ammonium alum+36½ p. ct. potassium alum	1.4586
$NH_4Al(SO_4)_2.12H_2O$	1.4594
$RbTi(SO_4)_2.12H_2O$	1.462–1.465 (red).
$RbIn(SO_4)_2.12H_2O$	1.4638
$CsGa(SO_4)_2.12H_2O$	1.4649
$CsIn(SO_4)_2.12H_2O$	1.4652
$KGa(SO_4)_2.12H_2O$	1.4653
$RbGa(SO_4)_2.12H_2O$	1.4658
$NH_4In(SO_4)_2.12H_2O$	1.4664
$NH_4Ga(SO_4)_2.12H_2O$	1.4684
$2Na_2AsO_4.NaF.19H_2O$	1.4693
$CaTi(SO_4)_2.12H_2O$	1.4736
$CsMn(SO_4)_2.12H_2O$	1.479–1.487 (red).
$KAl(SeO_4)_2.12H_2O$	1.4801
$CsCr(SO_4)_2.12H_2O$	1.4810
$KCr(SO_4)_2.12H_2O$	1.4814
$RbCr(SO_4)_2.12H_2O$	1.4815
$KFe(SO_4)_2.12H_2O$	1.4817
$RbFe(SO_4)_2.12H_2O$	1.4823
$CsFe(SO_4)_2.12H_2O$	1.4839
$NH_4Cr(SO_4)_2.12H_2O$	1.4842
$NH_4Fe(SO_4)_2.12H_2O$	1.4854
KCl	1.4903
RbCl	1.4930
Thallium alum+3 p. ct. potassium alum	1.4964
$TlAl(SO_4)_2.12H_2O$	1.4976
$RbRh(SO_4)_2.12H_2O$	1.5004–1.5023
$TlGa(SO_4)_2.12H_2O$	1.5066
$RbFe(SeO_4)_2.12H_2O$	1.5070
$CsRh(SO_4)_2.12H_2O$	1.5077
$NH_4Rh(SO_4)_2.12H_2O$	1.5103
$CsFe(SeO_4)_2.12H_2O$	1.5116
$Na_3(MgCl)(CO_3)_2$	1.5144
$NaClO_3$	1.5151
$TlCr(SO_4)_2.12H_2O$	1.5228
$2Na_3VO_4.NaF.19H_2O$	1.5230
$TlFe(SO_4)_2.12H_2O$	1.5236
$Na_3VO_4.10H_2O$	1.5305
$K_2Mg_2(SO_4)_3$	1.5329
NaCl	1.5442
$TlRh(SO_4)_2.12H_2O$	1.5480
RbBr	1.5530
KBr	1.5590
$Sr(NO_3)_2$	1.5667
$Ba(NO_3)_2$	1.5717
$NaBrO_3$	1.5943
CsCl	1.6418
NH_4Cl	1.6420
RbI	1.6474
K_2SnCl_6	1.6574
KI	1.6770
CsBr	1.6984
NH_4I	1.7031
MgO	1.7364
As_2O_3	1.7550
$Pb(NO_3)_2$	1.7838
CsI	1.7876
AgCl	2.0710
Sb_2O_3	2.0870
P (yellow)	2.1168
NiO	(red) 2.180; (blue) 2.390
CuI	2.3460
ZnS	2.3692
Cu_2O	2.7050
Si	3.7360

[a] Personal communication, G. L. Keenan.

TABLE 2.—*Uniaxial Positive Substances.*

Substance.	System.	ω_D	ϵ_D	$\epsilon-\omega$
$MgSiF_6.6H_2O$	Trig.	1.3439	1.3602	0.0163
$MnSiF_6.6H_2O$	Trig.	1.3570	1.3742	.0172
$FeSiF_6.6H_2O$	Trig.	1.3638	1.3848	.0210
MgF_2	Tetrag.	1.3780	1.3897	.0117
$CoSiF_6.6H_2O$	Trig.	1.3817(C)	1.3872(C)	.0055
$ZnSiF_6.6H_2O$	Trig.	1.3824	1.3956	.0132
$NiSiF_6.6H_2O$	Trig.	1.3910	1.4066	.0156
$Na_3PO_4.12H_2O$	Trig.	1.4458	1.4524	.0066
$K_2S_2O_6$	Trig.	1.4550	1.5153	.0603
$Na_3AsO_4.12H_2O$	Trig.	1.4567	1.4662	.0095
$Rb_2S_2O_6$	Trig.	1.4574	1.5078	.0504
$NaK_3(SO_4)_2$	Trig.	1.4901	1.4996	.0095
$Na_3VO_4.12H_2O$	Trig.	1.5095	1.5232	.0137
$Na_3VO_4.10H_2O$	Hexag. modification	1.5398	1.5475	.0077
$Fe_2(SO_4)_3.9H_2O$	Ditrig.	1.5519	1.5575	.0056
$MgPt(CN)_4.7H_2O$ [a]	Tetrag.	1.553−	1.553+	Very weak.
$Mg(OH)_2$	Trig.	1.5590 (red).	1.5795 (red).	.0205
$Ca(CeF)_2(CO_3)_3$	Dihex.	1.5690	1.6700	.101
$MgSnCl_6.6H_2O$	Trig.	1.5885	1.5970	.0085
K_4CdCl_6	Ditrig.	1.5906	1.5907	.0001
$(NH_4)_4CdCl_6$	Ditrig.	1.6038	1.6042	.0004
$CaSiO_3$ [b]	Hexag. modification	1.6150	1.6360	.021
$PbS_2O_6.4H_2O$	Trig.	1.6351	1.6531	.0180
$(NH_4)_3PdSO_3Cl_3.H_2O$ [c]	Trig.	1.6430	.....	Strong.
Li_2SiO_3 [d]	Rhomb.	1.65	1.67	.02
Be_2SiO_4	Rhomb.	1.6542	1.6700	.0158
$4NH_3.IrCl_3.H_2O$	Trig.	1.6576	1.6666	.0090
CuH_2SiO_4	Rhomb.	1.6580	1.7079	.0499
$P(C_2H_5)_4I$	Trig.	1.6600 (orange).	1.6680 (orange).	.008
$CaCeF(CO_3)_2$	Trig.	1.6742	1.7701	.0959

[a] Strong pleochroism; ⊥ opt. ax. more, ∥ axis less bluish.
[b] Anomalously biaxial, but always with very small ax. angle.
[c] ω Reddish yellow; ϵ dark carmine red.
[d] Indices approximate.

TABLE 2.—*Uniaxial Positive Substances*—Continued.

Substance.	System.	ω_D	ϵ_D	$\epsilon-\omega$
BeO	Hex	1.7190	1.7330	.014
$K_2Na(CrO_4)_2$	Trig	1.7278	1.7361	.0083
$AgBrO_3$	Ditetrag	1.8466	1.9200	.0734
Hg_2Cl_2	Ditetrag	1.9733	2.6559	.68265
$(PbCl)_2CO_3$	Tetrag	2.1140	2.1400	.026
AgI	Hex	2.230	.....	Weak
CdS	Hex	2.552 (red).. 2.688 (green).	.....	Weak.
SiC	Ditrig	2.7870	2.8320	.046
HgS	Trig	2.8540 (red).	3.2010 (red).	.347

TABLE 3.—*Uniaxial Negative Substances.*

Substance.	System.	ω_D	ϵ_D	$\omega-\epsilon$
Na_6SiF_6 [a]	Hex	1.300	1.296	0.004
$CuSiF_6.6H_2O$ [b]	Trig	1.4092	1.4080	.0012
$CaCl_2.6H_2O$	Trig	1.417	1.393	.024
$LiKSO_4$	Hex	1.4715	1.4721	−.0006
$BeSO_4.4H_2O$	Tetrag	1.4720	1.4395	.0325
$Pb_4(PbCl)(AsO_4)_3$	Hex	1.474 (red)	1.465 (red)	.009
$4Na_2SO_4.Na_2CO_3$	Hex	1.4807	1.4614	.0193
$Sr(OH)_2.8H_2O$	Tetrag	1.4991	1.4758	.0233
KH_2PO_4	Tetrag	1.5095	1.4684	.0411
$NiSO_4.6H_2O$ [c]	Tetrag	1.5109	1.4873	.0236
$K_3Cu(CN)_4$	Modification. Trig	Mean n 1.5215		Very weak.
$(NH_4)H_2PO_4$	Tetrag	1.5246	1.4792	.0454
$ZnSeO_4.6H_2O$	Tetrag	1.5291	1.5039	.0252
$SrS_2O_6.4H_2O$	Trig	1.5296	1.5252	.0044
$SrCl_2.6H_2O$ [d]	Trig	1.5364	1.4866	.0498
$NiSeO_4.6H_2O$	Tetrag	1.5393	1.5125	.0268
$CaS_2O_6.4H_2O$	Trig	1.5496	.....	.....
KH_2AsO_4	Tetrag	1.5674	1.5179	.0495
$(NH_4)H_2AsO_4$	Tetrag	1.5766	1.5217	.0549
$NaNO_3$	Ditrig	1.5874	1.3361	.2513
$(NH_4)_4Fe(CN)_6.2NH_4Cl.3H_2O$	Trig	1.6198	1.5922	.0276
$K_2CuCl_4.2H_2O$ [e]	Ditetrag	1.6365	1.6148	.0217
$Ca(OH)_2$	Hex	1.644	1.446	.198
$CaCO_3$	Trig	1.65837	1.4864	.17197
$4(NH_4)_2S_2O_3.AgBr.NH_4Br$	Tetrag	1.6769	1.6294	.0475
$CaMg(CO_3)_2$	Rhomb	1.68174	1.50256	.17918
$AlClSO_4.6Cu(OH)_2.3H_2O$ [f]	Ditrig	1.694 (green)	1.641 (green)	.053
$MgCO_3$	Trig	1.717	1.515	.202
$LiNO_3$ [g]	Trig	1.735	1.435	.300
$Na_{10}Cu_2Ag_4(S_2O_3)_8.6NH_3$ [h]	Tetrag	.....	1.7 (approx.)	.....
$(NH_4)_2CuCl_4.2H_2O$	Ditetrag	1.744	1.724	.020
$BaAg_2Cs_2(NCS)_7$	Ditetrag	1.7761	1.6788	.0973
$Cs_3Tl_2Cl_9$	Hex	1.784	1.774	.010
$K_2PtI_2(NO_2)_2.2H_2O$ [i]	Ditetrag	1.7909	1.6527	.1382
$BaCu_2Cs_2(NCS)_7$	Ditetrag	1.8013	1.6882	.1131
Ag_2HPO_4	Trig	1.8036	1.7983	.0053
$ZnCO_3$	Trig	1.818	1.6177	.2003
$MnCO_3$	Trig	1.82	1.5973	.2227
$SrCu_2Cs_3(NCS)_7$	Ditetrag	1.8535	1.6982	.1553
$FeCO_3$	Trig	1.873	1.633	.240
$CaWO_4$	Tetrag	1.9345 (red)	1.9185 (red)	.0160
$K_2H_2TeI_2O_{10}.2H_2O$	Trig	2.1121	2.0000	.1121
$PbWO_4$	Tetrag	2.2685	2.182	.0865
$PbMoO_4$	Tetrag	2.402 (red)	2.304 (red)	.098
$MnTiO_3$ [j]	Rhomb	2.481	2.21	.271
Ag_3SbS_3	Trig	3.084 (Li.)	2.881 (Li.)	.203
Ag_3AsS_3 [k]	Trig	3.0877	2.7924	.2953

[a] Indices determined by Duc de Chaulnes method.
[b] Color deep blue.
[c] Color emerald green
[d] Bolland gives 1.50, 1.52, 1.545 for n.
[e] Greenish blue. Pleochroism: Grass green, sky blue.
[f] Pleochroism weak: Green, blue-green.
[g] Personal communication, Dr. E. T. Wherry.
[h] Color deep blue. Pleochroism: Pale sapphire blue, deep cobalt blue.
[i] Color reddish yellow. Pleochroism: ∥ Chief axis greenish yellow, ⊥ orange.
[j] Color deep blood red. No distinct pleochroism.
[k] Pleochroism: Blood red, cochineal red.

TABLE 4.—*Biaxial positive substances.*

Substance.	System.	α_D	β_D	γ_D	$\gamma-\alpha$	$\gamma-\beta$	$\beta-\alpha$	Optical angle.	Dispersion.	Orientation.
$KH_2Mg_2B_{11}O_{20}.6H_2O$ (?)	Mon.	1.354						2H=100¼°		Ax. pl. ⊥b(010). Z∧c=64¾° in obtuse ∠β.
Na_3AlF_6	Mon.		1.364		Weak.	Weak.	Weak.	2E=59° 24′ (yellow).		Ax. pl. ⊥ (010). Z∧c=43° 54′ in acute ∠β.
$NaHPO_3.2\frac{1}{2}H_2O$	Mon.	1.4193	1.4309	1.4493	0.0300	0.0184	0.0116	2V (calc.)=77° 46′. 2V (obs.)=77° 38′.		Ax. pl. b(010). Z∧c=54° 33′ in acute ∠β.
$Na_2HPO_4.7H_2O$	Mon.	1.4412	1.4424	1.4526	.0114	.0102	.0012	2V=38° 50′ Na. 2E=57° 18′ Na.	Not perceptible.	Ax. pl. ⊥b(010). Z∧c=72° in acute ∠β.
$Na_2HPO_3.5H_2O$	Ortho.		1.4434		Weak.	Weak.	Weak.	2V=44° 7′		Ax. pl. c(001). Z∥a.
$Na_4P_2O_7.10H_2O$	Mon.	1.4499	1.4525	1.4604	.0105	.0079	.0026	2V=60° 29′. 2E=94° 3′.	Weak.	Ax. pl. ⊥b(010). Z⊥r(101).
$K_2Mg(SO_4)_2.6H_2O$	Mon.	1.4607	1.4629	1.4755	.0148	.0126	.0022	2V=47° 54′. 2E=72° 47′.		Ax. pl. b(010). Z∧c=103° 38′; Z∧a=1° 10′.
$Na_2HAsO_4.7H_2O$	Mon.	1.4622	1.4658	1.4782	.0160	.0124	.0036	2V=57° 7′. 2E=88° 59′.	Very small.	Ax. pl. ⊥b(010). Z∧c=65° in acute ∠β.
$K_2S_2O_8$	Tric.	1.4609	1.4669	1.5657	.1048	.0988	.0060	2V=29° 32′		
$Rb_2Mg(SO_4)_2.6H_2O$	Mon.	1.4672	1.4689	1.4779	.0107	.0090	.0017	2V=48° 46′. 2E=74° 40′.		Ax. pl. b(010). Z∧c=111° 14′; Z∧a=5° 15′.
$(NH_4)_2Mg(SO_4)_2.6H_2O$	Mon.	1.4716	1.4730	1.4786	.0070	.0056	.0014	2V=51° 11′. 2E=79° 11′.		Ax. pl. b(010). Z∧c=94° 58′; Z∧a=12° 8′.
$FeSO_4.7H_2O$	Mon.	1.4713	1.4782	1.4856	.0143	.0074	.0069	2V=88° 48′	Little.	Ax. pl. b(010). Z∧c=62° 28′ in acute ∠β.
$Rb_2Mn(SO_4)_2.6H_2O$	Mon.	1.4767	1.4807	1.4907	.0140	.0100	.0040	2V=67° 5′. 2E=109° 57′.		Z∧c=106° 57′; Z∧a=1° 0′. Ax. pl. b(010).
$K_2Fe(SO_4)_2.6H_2O$	Mon.	1.4759	1.4821	1.4969	.0210	.0148	.0062	2V=67° 7′. 2E=110° 10′.		Z∧c=101° 57′; Z∧a=2° 35′. Ax. pl. b(010).
$Na_4P_2O_6.10H_2O$	Mon.	1.4777	1.4822	1.5036	.0259	.0214	.0045	2V=48° 56′		Z∧c=39½° in acute ∠β. Ax. pl. b(010).
$K_2Zn(SO_4)_2.6H_2O$	Mon.	1.4775	1.4833	1.4969	.0194	.0136	.0058	2V=68° 14′. 2E=112° 29′.		Z∧c=100° 18′; Z∧a=4° 30′. Ax. pl. b(010).
$(NH_4)_2Mn(SO_4)_2.6H_2O$	Mon.		1.484					2V=69° 9′. 2E=114° 45′.		Z∧c=98° 36′; Z∧a=8° 26′. Ax. pl. b(010).
$Rb_2Cd(SO_4)_2.6H_2O$	Mon.	1.4798	1.4848	1.4948	.0150	.0100	.0050	2V=72° 26′		Z∧c=105° 53′; Z∧a=0° 0′. Ax. pl. b(010).
$Cs_2Mg(SO_4)_2.6H_2O$	Mon.	1.4857	1.4858	1.4916	.0059	.0058	.0001	2V=16° 25′. 2E=22° 50′.		Z∧c=136° 43′; Z∧a=29° 37′. Ax. pl. b(010).
NH_4ClO_4	Ortho.		1.486					2V=68°. 2E=112°.		Z∥b. Ax. pl. c(001).
$K_2Cu(SO_4)_2.6H_2O$	Mon.	1.4836	1.4864	1.5020	.0184	.0156	.0028	2V=46° 32′. 2E=72° 7′.		Z∧c=108° 33′; Z∧a=4° 5′. Ax. pl. b(010).
$K_2Co(SO_4)_2.6H_2O$ *a*	Mon.	1.4807	1.4865	1.5004	.0197	.0139	.0058	2V=68° 41′. 2E=114° 25′.		Z∧c=100° 5′; Z∧a=4° 50′. Ax. pl. b(010).

$Rb_2Fe(SO_4)_2.6H_2O$	Mon.	1.4815	1.4874	1.4977	.0162	.0103	.0059	2V=73° 21′ 2E=125° 12′		Z∧c=107° 9′; Z∧a=1° 25′. Ax. pl. b(010).
$Rb_2Zn(SO_4)_2.6H_2O$	Mon.	1.4833	1.4884	1.4975	.0142	.0091	.0051	2V=73° 33′ 2E=125° 46′		Z∧c=106° 43′; Z∧a=0° 50′. Ax. pl. b(010).
$Rb_2S_2O_8$	Mon.	1.4812	1.4888	1.5719	.0907	.0831	.0076	2V=35° 4′	Weak $\nu>\rho$	Z∧c=26½° in obtuse ∠β. Ax. pl. b(010).
$Na_2H_2P_2O_6.6H_2O$	Mon.	1.4855	1.4897	1.5041	.0186	.0144	.0042	2V=57° 20′ 2E=91° 22′		Z∧c=35° 17′ in obtuse ∠β. Ax. pl. b(010).
$(NH_4)_2Fe(SO_4)_2.6H_2O$	Mon.		1.490					2V=76° 52′ 2E=135° 42′	$\rho<\nu$	Z∧c=99° 43′; Z∧a=7° 5′. Ax. pl. b(010).
$Rb_2Cu(SO_4)_2.6H_2O$	Mon.	1.4886	1.4906	1.5036	.0150	.0130	.0020	2V=44° 42′ 2E=69° 8′		Z∧c=116° 28′; Z∧a=11° 10′. Ax. pl. b(010).
$K_2Ni(SO_4)_2.6H_2O$	Mon.	1.4836	1.4916	1.5051	.0215	.0135	.0080	2V=75° 16′ 2E=130° 57′		Z∧c=98° 42′; Z∧a=6° 18′. Ax. pl. b(010).
$Rb_2Co(SO_4)_2.6H_2O$	Mon.	1.4859	1.4916	1.5014	.0155	.0098	.0057	2V=75° 11′ 2E=130° 10′		Z∧c=106° 1′; Z∧a=0°. Ax. pl. b(010).
$(NH_4)_2Zn(SO_4)_2.6H_2O$	Mon.	1.4888	1.4930	1.4994	.0106	.0064	.0042	2V=79° 0′ 2E=144° 41′		Z∧c=96° 59′; Z∧a=9° 53′. Ax. pl. b(010).
K_2SO_4	Ortho.	1.4935	1.4947	1.4973	.0038	.0026	.0012	2V=67° 20′ 2E=111° 0′		Z∥c. Ax. pl. a(100).
$Na_2S_2O_6.2H_2O$	Ortho.	1.4820	1.4953	1.5185	.0365	.0232	.0133	2V=75° 14′ 2E=129° 33′		Z∥a. Ax. pl. b(010).
$Rb_2Ni(SO_4)_2.6H_2O$	Mon.	1.4895	1.4961	1.5052	.0157	.0091	.0066	2V=82° 0′ 2E=157° 0′		Z∧c=102° 38′; Z∧a=3° 25′. Ax. pl. b(010).
$Cs_2Mn(SO_4)_2.6H_2O$	Mon.	1.4946	1.4966	1.5025	.0079	.0059	.0020	2V=59° 57′ 2E=96° 57′		Z∧c=115° 27′; Z∧a=8° 20′. Ax. pl. b(010).
$UO_2(NO_3)_2.6H_2O$ [b]	Ortho.		1.4967					2V=44° 5′ (red). 2E=67° 6′	$\rho<\nu$	Z∥c. Ax. pl. b(010).
$(NH_4)_2Ni(SO_4)_2.6H_2O$ [c]	Mon.	1.489	1.498	1.508	.019	.010	.009	2V=86° 26′ 2H=88° 45′	$\rho<\nu$	Z∧c=96° 6′; Z∧a=10° 58′. Ax. pl. b(010).
$K_2Mg(SeO_4)_2.6H_2O$	Mon.	1.4969	1.4991	1.5139	.0170	.0148	.0022	2V=39° 38′ 2E=61° 7′		Z∧c=101° 18′; Z∧a=3° 0′. Ax. pl. b(010).
$KMgCl_3.6H_2O$	Ortho.		1.4992			Strong.		2V=69° 51′ 2E=118° 14′		Z∥c. Ax. pl. b(010).
$Cs_2Cd(SO_4)_2.6H_2O$	Mon.	1.4975	1.5000	1.5062	.0087	.0062	.0025	2V=67° 53′ 2E=114° 4′		Z∧c=116° 56′; Z∧a=9° 45′. Ax. pl. b(010).
$(NH_4)_2S_2O_8$	Mon.	1.4981	1.5016	1.5866	.0885	.0850	.0035	2V=24°	Moderate. $\nu>\rho$	Z∧c=26¾° in obtuse ∠β. Ax. pl. b(010).
$NH_4MgPO_4.6H_2O$	Ortho.		1.502					2E=47° 30′		Z∥b. Ax. pl. c(001).
$NaH_2AsO_4.2H_2O$	Ortho.	1.4794	1.5021	1.5265	.0471	.0244	.0227	2V=89° 11′		Z∥c. Ax. pl. b(010).
$Rb_2Mg(SeO_4)_2.6H_2O$	Mon.	1.5011	1.5031	1.5135	.0124	.0104	.0020	2V=47° 3′ 2E=73° 34′		Z∧c=106° 24′; Z∧a=1° 10′. Ax. pl. b(010).
$Cs_2Fe(SO_4)_2.6H_2O$	Mon.	1.5003	1.5035	1.5094	.0091	.0059	.0032	2V=74° 51′ 2E=132° 47′		Z∧c=118° 17′; Z∧a=11° 25′. Ax. pl. b(010).

[a] Pleochroism strong: X violet red, Y wine yellow, Z yellowish rose.
[b] X clearest, Y greenish yellow, Z deep citron yellow. Yellow green fluorescence.
[c] Absorption (Z=Y)>X.

TABLE 4.—*Biaxial positive substances*—Continued.

Substance.	System.	α_D	β_D	γ_D	$\gamma-\alpha$	$\gamma-\beta$	$\beta-\alpha$	Optical angle.	Dispersion.	Orientation.
$Cs_2Zn(SO_4)_2.6H_2O$	Mon.	1.5022	1.5048	1.5093	.0071	.0045	.0026	2V=74° 11′ 2E=130° 35′		Z∧c=120° 16′; Z∧a=13° 15′ Ax. pl. b(010).
$Cs_2Cu(SO_4)_2.6H_2O$	Mon.	1.5048	1.5061	1.5153	.0105	.0092	.0013	2V=43° 24′ 2E=68° 5′		Z∧c=132° 57′; Z∧a=26° 47′. Ax. pl. b(010).
$Na_2S_2O_3.5H_2O$	Mon.	1.4886	1.5079	1.5360	.0474	.0281	.0193	2V=80° 46′ 2E=154° 7′		Z∥b. Ax. pl.⊥b(010).
$Cs_2Co(SO_4)_2.6H_2O$	Mon.	1.5057	1.5085	1.5132	.0075	.0047	.0028	2V=81° 34′ 2E=156° 40′		Z∧c=40° 58′ in acute ∠β. Z∧c=116° 8′; Z∧a=9° 0′. Ax. pl. b(010).
$(NH_4)_2Mg(SeO_4)_2.6H_2O$	Mon.	1.5070	1.5093	1.5169	.0099	.0076	.0023	2V=54° 47′ 2E=88° 4′		Z∧c=90° 13′; Z∧a=16° 14′. Ax. pl. b(010).
$Na_2Ca(CO_3)_2.2H_2O$	Ortho.	1.5043	1.5093	1.5751	.0708	.0658	.0050	2V=31° 26′ 2E=48° 14′		Z∥b. Ax. pl. (001).
Rb_2SO_4	Ortho.	1.5131	1.5133	1.5144	.0013	.0011	.0002	2V=33° 0′ 2E=46° 20′		Z∥a. Ax. pl. c(001).
$Th(SO_4)_2.8H_2O$	Mon.		1.5168		Very weak.			2V=76° 20′	Small ρ<ν	Z∧c=65° in obtuse ∠β. Ax. pl. b(010).
$Cs_2Mg(SeO_4)_2.6H_2O$	Mon.	1.5178	1.5179	1.5236	.0058	.0057	.0001	2V=18° 35′ 2E=27° 27′		Z∧c=126° 47′; Z∧a=20° 30′. Ax. pl. b(010).
$K_2Zn(SeO_4)_2.6H_2O$	Mon.	1.5121	1.5181	1.5335	.0214	.0154	.0060	2V=66° 15′ 2E=112° 17′		Z∧c=99° 9′; Z∧a=5° 3′. Ax. pl. b(010).
$K_2Co(SeO_4)_2.6H_2O$	Mon.	1.5135	1.5195	1.5358	.0223	.0163	.0060	2V=63° 52′ 2E=106° 58′		Z∧c=100° 45′; Z∧a=3° 25′. Ax. pl. b(010).
$MgHPO_4.3H_2O$	Ortho.		1.5196					2V=44° 47′ 2E=70° 20′		Z∥c. Ax. pl. b(010).
$RbNO_3$	Ortho.	1.51	1.52	1.524	Weak.			Very small	ρ>ν	Z∥c. Ax. pl. b(010).
$Rb_2Zn(SeO_4)_2.6H_2O$	Mon.	1.5162	1.5222	1.5331	.0169	.0109	.0060	2V=75° 8′ 2E=138° 0′		Z∧c=103° 13′; Z∧a=2° 3′. Ax. pl. b(010).
$CaSO_4.2H_2O$	Mon.	1.5205	1.5226	1.5296	.00916	.00702	.00214	2V=58° 5′		Z∧c=75° 15′ in obtuse ∠β. Ax. pl. b(010).
$(NH_4)_2SO_4$	Ortho.	1.5209	1.5230	1.5330	.0121	.0100	.0021	2V=52° 12′ 2E=84° 6′		Z∥a. Ax. pl. b(010).
$K_3Cr(CN)_6$	Mon.	1.5221	1.5244	1.5373	.0152	.0129	.0023	2E=73° 32′		Z nearly ∥c. Ax. pl. b(010).
$K_2Ni(SeO_4)_2.6H_2O$	Mon.	1.5199	1.5248	1.5339	.0140	.0091	.0049	2V=72° 56′ 2E=129° 56′		Z∧c=97° 56′; Z∧a=6° 57′. Ax. pl. b(010).
$(NH_4)_2Fe(SeO_4)_2.6H_2O$	Mon.	1.5201	1.5260	1.5356	.0155	.0096	.0059	2V=76° 88′ 2E=142° 50′		Z∧c=96° 50′; Z∧a=9° 23′. Ax. pl. b(010).
$Na_4Fe(CN)_6.12H_2O$ *d*	Mon.	1.5193	1.5295	1.5436	.02432	.01410	.01022	2V=81° 25′		Z∧c=74° in obtuse ∠β. Ax. pl. (010).
$(NH_4)_2Zn(SeO_4)_2.6H_2O$	Mon.	1.5240	1.5300	1.5385	.0145	.0085	.0060	2V=82° 7′ 2E=170° 0′		Z∧c=93° 24′; Z∧a=12° 50′. Ax. pl. b(010).
$(NH_4)_2Co(SeO_4)_2.6H_2O$	Mon.	1.5246	1.5311	1.5396	.0150	.0085	.0065	2V=82° 1′		Z∧c=92° 41′; Z∧a=13° 42′. Ax. pl. b(010).

$BaS_2O_6.4H_2O$	Mon.		1.532 (red).					2V=87° 20′ (red) 2V=89° 42′ (green).		Ax. pl. ⊥(010) and very nearly ∥ (201).
$MgCd_2Cl_6.12H_2O$	Ortho.		1.533	1.5769		.0438		Very large	Small $\rho<\nu$	Z∥c. Ax. pl. a(100).
$Al(OH)_3$	Mon.	1.5347	1.5347	1.5577	.0230	.0230		Small		Ax. pl. ⊥(010). Z in (010).
$Cs_2Zn(SeO_4)_2.6H_2O$	Mon.	1.5326	1.5362	1.5412	.0086	.0050	.0036	2V=83° 6′ 2E=166° 6′		Ax. pl. b(010). Z∧c=111° 57′; Z∧a=5° 46′.
$(NH_4)_2Ni(SeO_4)_2.6H_2O$	Mon.	1.5291	1.5372	1.5466	.0175	.0094	.0081	2V=86° 14′		Ax. pl. b(010). Z∧c=89∠24′; Z∧a=16° 55′.
K_2SeO_4		1.5352	1.5390	1.5446	.0094	.0056	.0038	2V=76° 50′ 2E=146° 53′		Ax. pl. a(100). Z∥c.
$(Nd,Pr)_2(SO_4)_3.8H_2O$	Mon.	1.5392	1.5479	1.5592	.0200	.0113	.0087	2V=84° 10′		Z∥b.
$Y_2(SO_4)_3.8H_2O$	Mon.	1.5433	1.5490	1.5755	.0322	.0265	.0057	2V=50° 43′ 2E=83° 6′	$\rho<\nu$	Ax. pl. ⊥b(010). X almost exactly ⊥c(001).
$Pr_2(SO_4)_3.8H_2O$	Mon.	1.5399	1.5494	1.5607	.0208	.0113	.0095	2V=85° 27′		Ax. pl. ⊥b(010) and almost exactly ⊥c(001). Z∥b.
$Nd_2(SO_4)_3.8H_2O$ [e]	Mon.	1.5413	1.5505	1.5621	.0208	.0116	.0092	2V=83° 57′		Ax. pl. ⊥b(010). Z∥b. X almost exactly ⊥c(001).
$K_3Rh(CN)_6$	Mon.	1.5498	1.5513	1.5634	.0136	.0121	.0015	2V=39° 1′ 2E=63° 35′		Ax. pl. b(010). Z nearly ∥c.
$Sm_2(SO_4)_3.8H_2O$	Mon.	1.5427	1.5519	1.5629	.0202	.0110	.0092	2V=85° 56′		Ax. pl. ⊥b(010) and nearly ⊥c(001). Z∥b.
Rb_2SeO_4	Ortho.	1.5515	1.5537	1.5582	.0067	.0045	.0022	2V=68° 53′ 2E=121° 20′		Ax. pl. a(100). Z∥c.
$K_3Mn(CN)_6$ [f]	Mon.	1.5527	1.5547 (Li)	1.5710	.0183	.0163	.0020	2V=42° 53½′		Ax. pl. b(010). Z almost exactly ∥c.
$Li_2S_2O_6.2H_2O$	Ortho.	1.5487	1.5602	1.5788	.0301	.0186	.0115	2V=78° 16′ 2E=159° 45′		Ax. pl. c(001). Z∥a.
$(NH_4)_2SeO_4$	Mon.	1.5607	1.5630	1.5846	.0239	.0216	.0023	2V=37° 54′ 2E=60° 44′		Ax. pl. ⊥b(010) and nearly ∥c (001). Z∧c=113° 11′ in obtuse ∠β.
$K_2Cd(NO_2)_4$	Ortho.		1.565	1.608		.043		2E=80°(approx.)		Ax. pl. (100). Z∥c.
$K_3Fe(CN)_6$ [g]	Mon.	1.5660	1.5689	1.5831	.0171	.0142	.0029	2V=49° 10′ 2E=81° 29′		Ax. pl. b(010). Z∧c=3° 53′ in obtuse ∠β.
$CaSO_4$	Ortho.	1.5693	1.5752	1.6130	.0437	.0378	.0059	2V=43° 44½′		Ax. pl. b(010). Z∥a.
$Ba(ClO_3)_2.H_2O$	Mon.	1.5622	1.577	1.635	.0728	.058	.0148	2V=55° 30′		Ax. pl. b(010). Z∧c=23¾° in acute ∠β.
$Ca_2Fe(CN)_6.12H_2O$	Tric.	1.5700	1.5818	1.5961	.0261	.0143	.0118	2V=85° 12′		X nearly ⊥c(001). One optic axis nearly ⊥b(010).
$BeBO_3(Be.OH)$	Ortho.	1.5595	1.5908	1.6311	.0716	.0403	.0313	2V=87° 7′		Ax. pl. b(010). Z∥c.
$K_2Cr_2O_7.Hg(CN)_2.2H_2O$	Ortho.		1.591 (red).					2V=57° 18′ 2E=99° 22′	Very strong	Ax. pl. a(100). Z∥c.

[d] Y>X>Z.
[e] Pleochroism very weak: ∥(010) somewhat deeper colored.
[f] Pleochroism weak: X brick red, Y scarlet red, Z blood red.
[g] X orange-dawn red, Y hyacinth-cherry red, Z cherry red. Y>Z>X.

TABLE 4.—*Biaxial positive substances*—Continued.

Substance.	System.	α_D	β_D	γ_D	$\gamma-\alpha$	$\gamma-\beta$	$\beta-\alpha$	Optical angle.	Dispersion.	Orientation.
$Fe_3(PO_4)_2.8H_2O$	Mon.		1.592					2V=73° 10′		Ax. pl ⊥ (010). Z∧c=6½° in obtuse ∠β.
$Ca_2B_6O_{11}.5H_2O$	Mon.	1.5863	1.5920	1.6139	.02772	.02196	.00576	2V=54° 52′; 2E=95° 15′		Ax. pl. ⊥ (010). Z∧c=83° in obtuse ∠β.
$Na_2Ru(NO_2)_5.2H_2O$ *h*	Mon.	1.5889	1.5943	1.7163	.1274	.1220	.0054	2V=25° 14′; 2E=41° 8′		Ax. pl. b(010). Z∧c=84° 18′ in acute ∠β.
$BaS_2O_6.2H_2O$	Mon.	1.5860	1.5951	1.6072	.0212	.0121	.0091	2V=82° 26′		Ax. pl. b(010). Z∧c=13¼° in acute ∠β.
$(AlO)_3BO_3$	Ortho.	1.586	1.603	1.623	.037	.020	.017	2V=87° 5′		Ax. pl. b(010). Z∥c.
$CaH_4Si_3SnO_{11}$	Ortho.	1.609	1.6125	1.619	.010	.0065	.0035	2V=69½°	ρ<ν	Ax. pl. (010). Z∥c.
$SrSO_4$	Ortho.	1.6220	1.6237	1.6237	.0017			2V=51° 45′; 2E=88° 38′		Ax. pl. b(010). Z∥a.
$Na_6H_8(MoO_4)_7.18H_2O$	Mon.		1.627		Strong.			2V=84° 6′		Ax. pl. ⊥ b(010). Z∧c=84½° in acute ∠β.
$BaSO_4$	Ortho.	1.6369	1.6381	1.6491	.0122	.0110	.0012	2V=37° 28′; 2E=63° 12′		Ax. pl. b(010). Z∥a.
$Ca_4P_2O_9$	Mon.		Mean n=1.64		Rather strong.			2V=20° (red); 2V=40° (blue)		Ax. pl. b(010). Z nearly ∥c.
$BaCl_2.2H_2O$	Mon.	1.635	1.646	1.660	.025	.014	.011	2V=83° 46′		Ax. pl. (010). Z∧c=8° in obtuse ∠β.
$CdCl_2.2\frac{1}{2}H_2O$	Mon.		1.6513					2V=56° 27′; 2E=100° (air) =53°30′(glass)	Imperceptible.	Ax. pl. (010). Z∧c=1° 40′ in obtuse ∠β.
$Mg_3(BO_3)_2$	Ortho.	1.6527	1.6537	1.6748	.0221	.0211	.0010	2E=43° 18′	Weak ρ>ν	Ax. pl. b(010). Z∥c.
$Na_2SO_4.Cu_2(CuOH)_2(SO_4)_3.2H_2O$	Mon.	1.6491	1.6555	1.7143	.0652	.0588	.0064	2V=36° 48′	Strong	Z∧c=12° in acute ∠β. Ax. pl.=symmetry plane.
$K_2PtBr_2(NO_2)_2.H_2O$	Tric.	1.626	1.6684	1.757	.131	.0886	.0424	2V=72° 21′		Ext. angle on (20T) with edge (00T:20T)=33°.
$BaPtCy_4.4H_2O$	Mon.	1.6704		1.8982	.22761			2E=31° 16′		Ax. pl. (010). Z∧c=1° 20′ in acute ∠β.
$Na_2Cr_2O_7.2H_2O$	Mon.	1.6610	1.6994	1.7510	.0900	.0516	.0384	2V=83° 42′		Ax. pl. ⊥ b(010). Z∧c=13° in obtuse ∠β.
$SrCr_2O_7.3H_2O$	Mon.	1.7146	1.7174	1.812	.0974	.0946	.0028	2V=20° 28′; 2E=37° 26′	ρ<ν	Ax. pl. b(010). Z∧c=78° 8′ in obtuse ∠β.
AlO.OH	Ortho.	1.702	1.722	1.750	.048			2V=84° 20′		Ax. pl. (010). Z∥a.
$BaBr_2.2H_2O$	Mon.	1.7129	1.7266	1.7441	.0312	.0175	.0137	2V=83° 49′		Ax. pl. (010). Z nearly ⊥ (100). Z∧c=89° 35′ in obtuse ∠β.

$AgNO_3$	Ortho.	1.729		1.788	.059			2V=62° 16′ 2E=125° 44′	$\rho < \nu$	Ax. pl. a(100). Z∥c.
$K_2Cr_2O_7$	Tric.	1.7202	1.7380	1.8197	.0995	.0817	.0178	2V=51° 53′ 2E=98° 58′		Ax. pl. nearly ⊥c(001).
$MgW_4O_{13}.8H_2O$	Mon.		1.74					2V=77° 50′	Weak $\rho < \nu$	Ax. pl. ⊥b(010). X∧c=66° in acute ∠β.
$Na_2Si_2(9/11Ti,2/11Zr)_2O_9$	Ortho.	1.7431		1.7876	.0445			2E=72°		Ax. pl. (100). Z∥b.
$Sr_3W_{12}SiO_{40}.16H_2O$	Mon.		1.749		Rather strong.			2V=86° 50′	Very strong $\rho < \nu$	Ax. pl. ⊥b(010). Z∧c=17° in acute ∠β.
Tl_2SO_4	Ortho.	1.8600	1.8671	1.8853	.0253	.0182	.0071	2V=68° 4′ 2H=77° 43′		A=γ, b=β, c=α. Z∥a; X∥c. Ax. pl. b(010).
$PbSO_4$		1.8771	1.8823	1.8937	.0166	.0114	.0052	2V=75° 24′		Ax. pl. b(010). Z∥a.
S	Ortho.	1.9579	2.0377	2.2452	.28725	.20746	.07979	2V=68° 58′		Ax.pl. b(010). Z∥c.
$PbCl_2$	Ortho.	2.1992	2.2172	2.2596	.0604	.0424	.0180	2V=66° 12′		Ax.pl. b(010). Z∥a.
$PbCrO_4$			2.42		Extraordinarily strong.			2V=54°	Weak $\rho > \nu$	Ax.pl. b(010). Z∧c=5½ in obtuse ∠β.

[h] Vibration ∥ Z, orange; ∥X, yello w

TABLE 5.—*Biaxial negative substances.*

Substance.	System.	α_D.	β_D.	γ_D.	$\gamma-\alpha$.	$\gamma-\beta$	$\beta-\alpha$	Opt. Angle.	Disp.	Orientation.
$Na_2SO_4.10H_2O$	Mon.	1.394	1.396	1.398	0.004			2V=80° 26′ 2E=122° 48′(red)		Ax.pl.⊥b(010). X∥b.
$Na_2HPO_4.12H_2O$	Mon.	1.4321	1.4361	1.4373	.0052	0.0012	0.0040	2V=56° 43′ 2E=86° 1′	Distinct Inclined	Ax. pl.b(010). X∧c=31° in acute∠β.
$Na_2HAsO_4.12H_2O$	Mon.	1.4453	1.4496	1.4513	.0060	.0017	.0043	2V=65° 13′	Small horizontal.	Ax.pl.⊥b(010). X∧c=1° in acute∠β.
$MgSO_4.7H_2O$	Ortho.	1.4326	1.4554	1.4609	.02835	.00550	.02285	2V=51° 35′ 2E=78° 20′		Ax.pl.c(001). X∥b.
$NaH_2PO_4.2H_2O$	Ortho.	1.4401	1.4629	1.4815	.0414	.0186	.0228	2V=82° 50′		Ax.pl.b(010). X∥c.
$Na_2H_2P_2O_7.6H_2O$	Mon.	1.4599	1.4645	1.4649	.0050	.0004	.0046	2V=31° 56′ 2E=47° 31′		Ax.pl.⊥b(010). X∧c=42½ in acute∠β.
Li_2SO_4[a]	Mon.		1.465		Rather weak.			2V=72° 58′	Small ρ>ν.	Ax.pl.⊥(010). X∧c=31° in acute∠β.
$Na_2B_4O_7.10H_2O$	Mon.	1.4468	1.4686	1.4715	.0247	.0029	.0218	2V=39° 36′ 2E=59° 23′		Ax.pl.⊥b(010). X∥b; Z∧c=55° 35′ in acute∠β.
$Na_3HP_2O_6.9H_2O$	Mon.	1.4653	1.4738	1.4804	.0151	.0066	.0085	2V=82° 0′		Ax.pl.⊥b(010). X∧c=11° in acute∠β.
$K_2H_2P_2O_6.3H_2O$	Ortho.	1.4768	1.4843	1.4870	.0102	.0027	.0075	2V=62° 0′	Very small ρ<ν.	Ax.pl.a(100). X∥c.
$NaH_2PO_4.H_2O$	Ortho.	1.4557	1.4852	1.4873	.0316	.0021	.0295	2V=29° 22′ 2E=44° 14′		Ax.pl.b(010). X∥a.
$ZnSO_4.7H_2O$	Ortho.	1.4620	1.4860	1.4897	.0277	.0037	.0240	2E=70° 23′	ρ>ν.	Ax.pl.c(001). X∥b.
$NiSO_4.7H_2O$	Ortho.	1.4669	1.4888	1.4921	.0252	.0033	.0219	2V=41° 56′ 2E=64° 24′(red).		Ax.pl.c(001). X∥b.
$MgSeO_4.6H_2O$	Mon.	1.4856	1.4892	1.4911	.0055	.0019	.0036	2V=28° 12′	Strong ρ>ν.	Ax.pl.b(010). X∧c=27° in acute∠β.
$MgSO_4.5H_2O$	Tric.		1.491					2V=45° 8′	ρ<ν.	X⊥ a plane which deviates little from (010).
$(NH_4)_2Cu(SO_4)_2.6H_2O$[b]	Mon.		1.494 (red) 1.502 (blue)					2V=71° 21′ 2E=121° 39′	Considerable ρ>ν.	Ax.pl.b(010). X∧c=18° 39′; X∧a=87° 27′.
$Na_2Mg(SO_4)_2.4H_2O$ [29]	Mon.		1.500 (red).					2V=70° 5′ 2E=119°		Ax.pl.(010). X∧c=45° (red) in acute∠β.
$BeSeO_4.4H_2O$	Ortho.	1.4664	1.5007	1.5027	.0363	.0020	.0343	2V=26° 43′ 2E=40° 34′		Ax.pl.a(100). X∥c.
$MgCO_3.3H_2O$[c]	Ortho.	1.495	1.501	1.526	.031	.025	.006	2V=53° 5′ 2E=84° 15′		Ax.pl.c(001). X∥a.
$Ba(OH)_2.8H_2O$	Mon.	1.4710	1.5017	Nearly=β.			.0301	2V=8° 33′ 2E=20° 9′		Ax.pl.⊥(010). X nearly⊥c(001).
KNO_3	Ortho.	1.3346	1.5056	1.5064	.1718	.0008	.1710	2V=7° 12′ 2E=10° 51′		Ax.pl.a(100). X∥c.
$Ce_2(S_2O_6)_3.15H_2O$	Tric.		1.507					2V=88° 52′	Weak ρ>ν.	Both axial figures visible through c(001).

$KClO_3$[b]	Mon.	1.440	1.515	1.525				2V=28° 15′ 2E=43°	$\nu>\rho$	Ax.pl.⊥b(010). X∧c=57½ in obtuse∠β.
$NaHCO_3.Na_2CO_3.2H_2O$	Mon.		1.5073		Strong.			2V=76° 16′		Ax.pl.∧c(001)=5¾° in obtuse ∠β. X∥b.
$Cs_2Ni(SO_4)_2.6H_2O$	Mon.	1.5087	1.5129	1.5162	.0075	.0033	.0042	2V=87° 21′		Ax.pl.b(010). X∧c=24° 7′; X∧a=82° 55′.
$Na_2Ca(CO_3)_2.5H_2O$	Mon.	1.4435	1.5156	1.5233	.0798	.0077	.0721	2V=35° 4′ 2E=52° 4′		Ax.pl.⊥b(010). X∥b.
$K_2Ca(SO_4)_2.H_2O$	Mon.	1.5000	1.5170	1.5183	.0183	.0013	.0170	2V=26° 44′ 2E=44° 42′		Ax.pl.⊥(010). X∧c=87° 14′.
$CoSeO_4.6H_2O$	Mon.		1.5225	1.5227		.0002		2V=7° 13′ 2E=11° 0′	$\rho>\nu$	Ax.pl.b(010). X∧c=34° 42′ in acute∠β.
$K_2Cu(SeO_4)_2.6H_2O$[c]	Mon.	1.5096	1.5235	1.5387	.0291	.0152	.0139	2V=88° 12′		Ax.pl.b(010). X∧c=10° 53′; X∧a=92° 26′.
$K_2H_2P_2O_6.2H_2O$	Mon.	1.4893	1.5314	1.5363	.0470	.0049	.0421	2V=36° 9′	Very weak $\rho<\nu$	Ax.pl.⊥b(010). X∧c=36° 30′ in acute∠β.
$(NH_4)_2Cu(SeO_4)_2.6H_2O$	Mon.	1.5213	1.5355	1.5395	.0182	.0040	.0142	2V=55° 24′ 2E=91° 6′		Ax.pl.b(010). X∧c=12° 20½′; X∧a=93° 12′
$(NH_4)HCO_3$	Ortho.	1.4227	1.5358	1.5545	.1318	.0187	.1131	2V=41° 38′ 2E=66° 10′		Ax.pl.b(010). X∥a.
$2MgHBO_3.MgSO_4.3\frac{1}{2}H_2O$	Ortho.	1.5272	1.5362	1.5443	.0171	.0081	.0090	2V=86° 52′		Ax.pl.(010). X∥c.
$CuSO_4.5H_2O$	Tric.	1.5140	1.5368	1.5433	.0293	.0065	.0228	2V=56° 2E=93°	$\rho<\nu$	
$BaSiO_3.6H_2O$	Ortho.	1.542	1.548	Nearly=β.			.006	2V=39° 40′ 2E=59° 40′		Ax.pl.b(010). X∥a.
$MgCrO_4.7H_2O$	Ortho.	1.5211	1.5500	1.5680	.0469	.0180	.0289	2V=75° 28′	$\rho<\nu$	Ax.pl.c(001). X∥b.
$NaH_2AsO_4.H_2O$	Ortho.	1.5382	1.5535	1.5607	.0225	.0072	.0153	2V=67° 57′ 2E=120° 28′		Ax.pl.b(010). X∥c.
$NaBePO_4$	Ortho.	1.5520	1.5579	1.5608 (?)	.0088	.0029	.0059	2E=121° 1′		Ax.pl.(100). X∥c.
Cs_2SO_4	Ortho.	1.5598	1.5644	1.5662	.0064	.0018	.0046	2V=65° 20′ 2E=115° 40′		Ax.pl.b(010). X∥c.
$CdSO_48/3H_2O$	Mon.		1.565					2V=88° 9′		Ax. pl.⊥b(010). X∥b.
Li_2CO_3	Mon.	1.428	1.567	1.572	.144	.005	.139	2E=24°		Ax. pl. nearly ∥ a(100). X almost exactly ∥c.
$NH_3KPtCl_3.H_2O$[f]	Ortho.	1.5438	1.5754				.0316	2V=64°		Ax. pl. a(100). X∥c.
$K_4Fe(CN)_6.3H_2O$	Mon.		1.5772					2V=78° 10′	Weak $\rho>\nu$	Ax. pl. ⊥(010). X∧c=31° 50′ in obtuse∠β.
$K_4Ru(CN)_6.3H_2O$	Mon.		1.5837					2V=54° 0′		Ax. pl. ⊥(010). X∧c=32° 10′ in obtuse∠β.
$MgPt(CN)_4.C_3H_8O_3.5H_2O$	Mon.		1.584					2V=17° 39′		Ax. pl. b(010). X∧c=30° in obtuse∠β.

[a] Bolland gives 1.49, 1.48 for n.
[b] X reddish, Y dark blue, Z clearer blue. Indices: personal communication, E. T. Wherry.
[29] Bolland gives 1.485, 1.49 for n (?).
[f] A yellowish red, B reddish yellow, C deep yellow or red.

[c] α calculated.
[d] Bolland gives 1.47 and 1.54 for n.
[e] If indices are correct is positive, for $\gamma-\alpha>\beta-\alpha$.

TABLE 5.—*Biaxial negative substances*—Continued.

Substance.	System.	α_D.	β_D.	γ_D.	$\gamma-\alpha$.	$\gamma-\beta$	$\beta-\alpha$	Opt. angle.	Disp.	Orientation.
$CaHAsO_4.2H_2O$	Mon.	1.5825	1.5891	1.5937	.0112	.0046	.0066	2V=79° 24′		Ax. pl. ⊥b(010). X∧c=69° 40′ in obtuse ∠β.
Cs_2SeO_4	Ortho.	1.5989	1.5999	1.6003	.0014	.0004	.0010	2V=71° 49′; 2E=132° 20′		Ax. pl. c(001). X∥b.
$K_2Li_2Fe(CN)_6.3H_2O$ *g*	Mon.	1.5883	1.6007	1.6316	.0433	.0309	.0124	2V=65° 56′		Ax. pl. (010). X∧c=44° 10′ in acute ∠β.
$K_4Os(CN)_6.3H_2O$	Mon.		1.6071					2V=47° 0′		Ax. pl. ⊥(010). X∧c=30° 10′ in obtuse ∠β.
$CaPtCy_4.5H_2O$	Ortho.	1.6226		1.7643	.14164			2E=86½°		X∥c.
$NH_4PtCl_3.C_2H_4.H_2O$	Mon.	1.623		1.702				2E=32½°	ν>ρ	Ax. pl. ⊥(010). X∧c=8½° in obtuse ∠β.
$KPtCl_3.C_2H_4.H_2O$ *h*	Mon.	1.627		1.717				2E=47°		Ax. pl. ⊥(010). X∧c=22° in obtuse ∠β.
$CaPO_4(BeOH)$	Mon.		1.630					2V=72°	ρ>ν	Ax. pl. (010). X∧c=2½° in acute ∠β.
$Na_6Mo_5P_2O_{23}.14H_2O$	Ortho.	1.5962	1.6411	1.6520	.0558	.0109	.0449	2V=51° 18½′; 2E=90° 35′		Ax. pl. a(100). X∥b.
$BaCdCl_4.4H_2O$	Tric.		1.651		Not strong.			2H=69° 33′	ρ<ν	X nearly ⊥m(110). Ext. angle on (110)=10⅔°, on (010)=5⅔°, on (100)=2½°, on (110)=4½°.
$(NH_4)_4Ru(NO)(OH)Cl_6H_2O$	Mon.		1.6548					2V=56° 20′	Very weak ρ<ν	Ax. pl. b (010). X∧c=44° 20′ in acute ∠β.
$Ca(BO_2)_2$	Ortho.	1.540	1.656	1.682	.142	.026	.116	2E=90° 24′		Ax. pl. c(001). X∥a.
$Ag_2S_2O_6.2H_2O$	Ortho.	1.6272	1.6573 (C)	1.6601	.0329	.0028	.0301	2V=33° 21′; 2E=56° 48′		Ax. pl. c(001). X∥b.
$Co_3(AsO_4)_2.8H_2O$ *i*	Mon.	1.6263	1.6614	1.6986	.0723	.0372	.0351			X∥b.
$SrCO_3$	Ortho.	1.5155	1.664	1.666	.150	.002	.148	2V=6° 22′; 2E=10° 36′		Ax. pl. (100). X∥c.
$K_2HgCl_4.H_2O$	Ortho.	1.648	1.678	1.699	.051	.021	.030	2V=78° 25′	Very considerable. ρ>ν.	Ax. pl. c(001). X∥a.
$Na_3AsS_4.8H_2O$	Mon.		1.6802		Weak.			2V=87° 44′		Ax. pl. b(010). X∧c=81° 11′ in obtuse ∠β.
$CaCO_3$	Ortho.	1.5299	1.6809	1.6854	.15543	.00443	.15100	2V=18° 11′; 2E=30° 52′		Ax. pl. (100). X∥c.
$CaBa(CO_3)_2$	Mon.	1.525	1.684	1.686	.161	.002	.159	2E=23° 15′(red); 2E=22° 47′(blue)		Ax. pl. ⊥(010). X∧c=64⅓° in obtuse ∠β.
$BaCdBr_4.4H_2O$	Tric.		1.702					2V=70° 13′	ρ<ν	
K_2CrO_4	Ortho.		1.7131 (C)					2V=51° 40′; 2E=97° 30′	Weak ρ>ν	Ax. pl. a(100). X∥b.
$CaBe_3(Mn, Fe, Mg)_2(SiO_4)_3$	Tric.	1.7148	1.7202	1.7253	.0105	.0051	.0054	2V=83° 29′	Very small	Ax. pl. nearly ⊥c(100). X almost ⊥c(001).
$CaMnSiO_4$	Ortho.	1.686	1.722	1.735	.049	.013	.036	2V=60° 51′; 2E=121° 30′		Ax. pl. c(001). X∥b.

$Mn_3B_4O_9$	Tric.	1.617	1.738	1.776	.159	.038	.121			X∧⊥c(001)=27° 43′. X∧⊥a(100)=29° 11′.
$BaCO_3$	Ortho.		1.740					2E=26° 30′	Scarcely perceptible. ρ>ν	Ax. pl. (010). X∥c.
$CuPO_4(CuOH)$	Ortho.		1.743					2V=81° 8′		Ax. pl. c(001). X∥b.
$Ba_2W_{12}SiO_{40}.16H_2O$	Mon.		1.816		Rather strong.			2V=78° 44′	Very strong ρ>ν	Ax. pl. ⊥b(010). X∥b.
$TlNO_3$	Ortho.	1.817						2E=111° 16′ (red). 2E=114° 59′ (blue)		Ax. pl. b(010). X∥c.
$PbSO_4.Cu(OH)_2$	Mon.	1.8090	1.8380	1.8593	.0503	.0213	.0290	2V=79° 59′		Ax. pl. ⊥(010). X∧c=24° in acute ∠β.
$Pb(SO_4)_4\ (PbOH)_6.2\ Cu(CO_3)_4\ (CuOH)_6$.	Ortho.		1.846 (red)					2V=82° 37′		Ax. pl. (100).
$Cu_2(OH)_3Cl$	Ortho.	1.831	1.861 (green)	1.880	.049	.019	.030	2V=74° 56′		Ax. pl. (100). X∥b.
$(CuOH)_2CO_3$	Mon.		1.87 1.88					2V=44° 7′ 2E=89° 18′ (yellow).		Ax. pl. (010). X∧c=23½° in obtuse ∠β.
Tl_2SeO_4	Ortho.	1.9493	1.9592	1.9640	.0147	.0048	.0099	2V=72° 58′		α∥b, β∥c, γ∥a. X∥b; Z∥a. Ax. pl. c(001).
$PbCO_3$	Ortho.	1.8037	2.0763	2.0780	.2743	.0017	.2726	2V=8° 14′ 2E=17° 8′		Ax. pl. (010). X∥c.
$Pb(OH)Cl$ *j*	Ortho.	2.0767	2.1161	2.1580	.0813	.0419	.0394	2V=81° 32′		Ax. pl. b(010). X∥a.
$Pb(Tl, Ag)_2(AsS_2)_4$	Ortho.	3.078	3.176	3.188	.110	.012	.098	2V=37° 34′		Ax. pl. (100). X∥b.
$AgAsS_2$	Mon.		Mean n=3.27					2V=65°		Ax. pl. (010). X∧⊥(100)=6½° in obtuse ∠β.

g If indices are correct, is positive.
i If indices are correct, is positive.

h Pleochroism weak. b greenish, all others brownish.
j If indices are correct, is positive.

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SALES METHODS AND POLICIES OF A GROWERS' NATIONAL MARKETING AGENCY.

A Study of the Organization and Achievements of Twenty-six Years of Cooperative Marketing by Part of the Cranberry Growers of the United States.

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Columbia University in the City of New York and Bureau of Agricultural Economics, U. S. Department of Agriculture cooperating.

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INTRODUCTION.

The cranberry has fared better in times of stress than other farm products. For this reason the marketing methods of the cranberry growers have been analyzed in detail in the hope that this analysis may furnish suggestions that will be helpful in the marketing of other farm products. Although this discussion deals specifically with the marketing of cranberries by cooperative methods, it is not written for the cranberry grower alone. It is addressed to all growers interested in successful marketing methods. It deals with the economic and not the legal aspects of the subject.

The noteworthy achievements of the cranberry growers are the outcome of evolutionary practices based upon 26 years of experience in selling through growers' cooperative agencies. The results of organized efforts in this industry are the more remarkable because of

the unusual difficulties which must be overcome in the successful marketing of cranberries.

The cranberry growers of the United States are widely separated. The three largest producing districts are in Massachusetts, New Jersey, and Wisconsin. Cooperative marketing involved the coordination of the growers in these three widely separated localities into one central selling association.

The consuming public looks upon the cranberry as a luxury rather than a prime necessity. It is generally considered a holiday fruit. Thanksgiving and Christmas bring the turkey with its cranberry sauce to the minds of the American people, but Thanksgiving and Christmas demands alone are not sufficient to support the industry. Figure 1 shows the seasonal demand for this fruit. Over three-

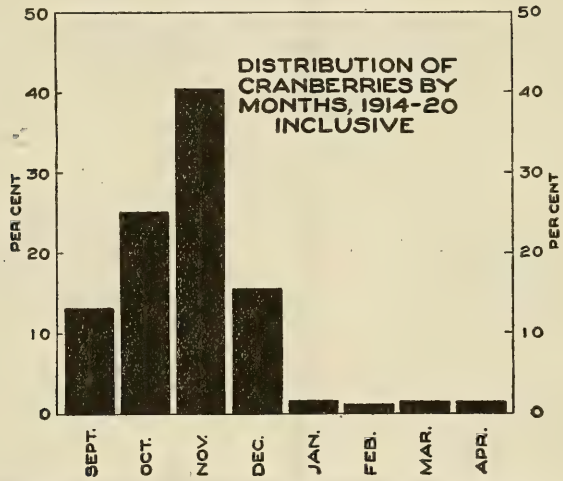

FIG. 1.—A problem of vital importance to cranberry growers is that of lengthening the consumption period. Since a large portion of the cranberry crop is now packed and shipped during three months, the grower is forced to maintain extensive screening and packing equipment which is idle all but a small part of the year.

fourths of the crop is marketed during October, November and December. This heavy demand during so short a period makes it impossible for many growers to maintain the necessary packing and screening equipment. Therefore, one of the important tasks before the growers is that of lengthening the consumption period. Furthermore, the consumption of the fruit depends, to no small extent, upon the supply and price of sugar.

Add to these difficulties the element of perishability and the problem of establishing uniform grades, and it can readily be seen that the successful marketing of cranberries is no small undertaking.

A few of the outstanding accomplishments of cooperation in this industry are:

1. A reputation for quality has been built up by establishing and maintaining uniform grades and packs.

2. Marketing risks have been distributed equally among all members of the association by means of pooling systems. High and low-priced orders, losses and gains through market fluctuations, and the risks of transportation, are equally divided. Pools are, in effect, a form of market insurance.

3. An advertising fund sufficient to bring the berries forcefully to the attention of the consuming public has been created by means of a small assessment per barrel. Through advertising, consumption has been increased to an extent sufficient to care for increased pro-

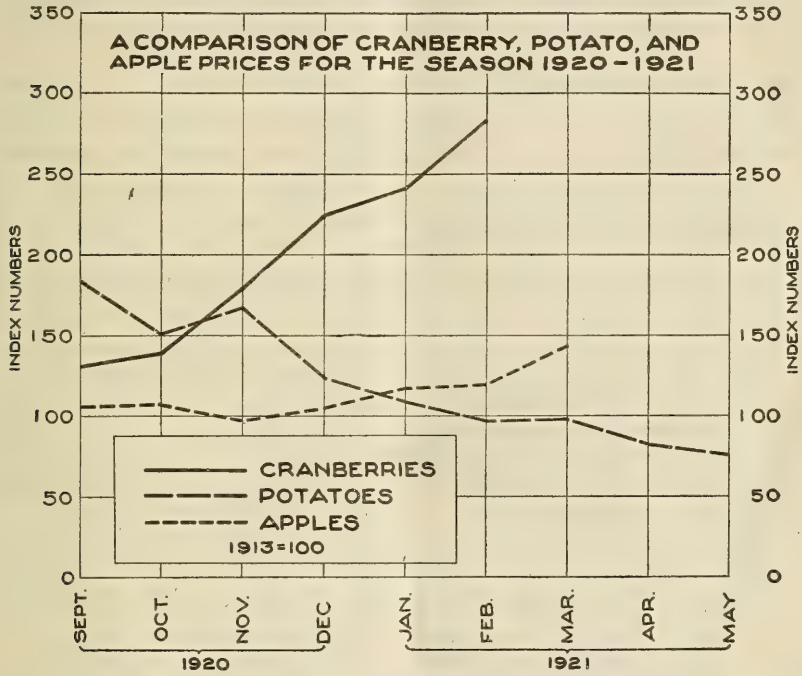

FIG. 2.—Apples, a staple fruit, and potatoes, a staple vegetable, did not fare so well as cranberries during the selling season of 1920–21.

duction. Advertising has played an important part in the achievements of the cranberry growers.

4. "Glutted" and "famine" markets have been eliminated by coordinating distribution from the three districts, and as a result market prices have been stabilized. Cranberry prices did not rise during the war in proportion to other prices. On the other hand, cranberry prices did not fall during the selling season of 1920–21, when prices of practically all farm products, as well as other commodities, declined rapidly. (See figs. 2 and 3.) This stabilization of the market, together with the establishment of uniform methods of dealing with the wholesale and retail trade, has built up a good-will relationship with the trade to a degree which could not have been reached by the growers individually.

5. The goal of cooperative marketing of perishable food products is to obtain the highest average price which will move the entire supply year after year. To this end the adjustment of demand forces to the supply of any given year requires a close study of ever-changing conditions affecting the price of the product. By cooperation the cranberry growers are in a position to employ specialized business men capable of advising them regarding supply and demand forces and their probable effect upon price and market conditions. Thus

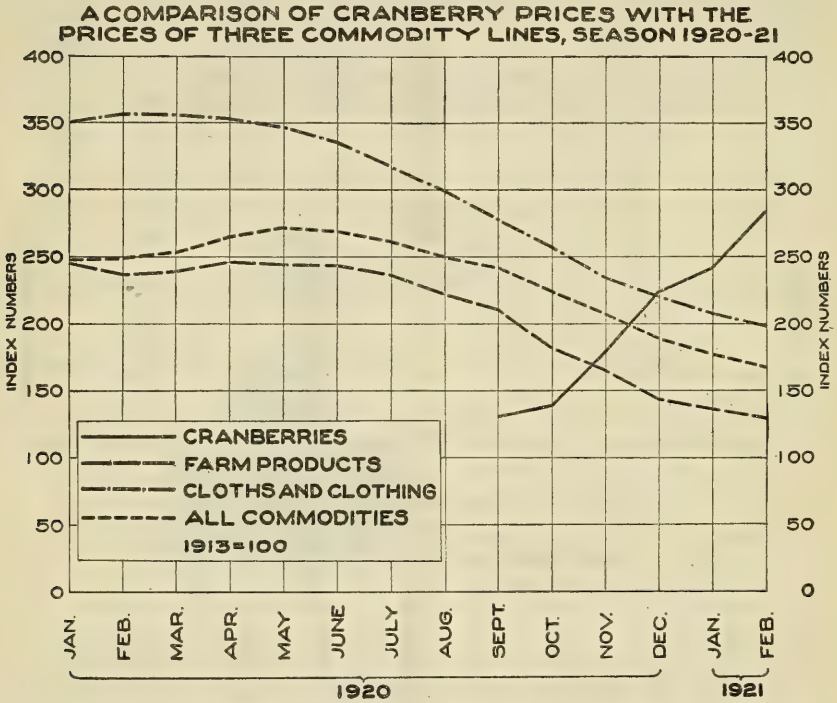

FIG. 3.—Prices of practically all commodity lines fell rapidly during the cranberry selling season of 1920–21. Cranberries were an exception to the rule. It should be noted that the price of cranberries at the opening of the season was at a level much lower in proportion to the 1913 price than were the prices of the other commodity lines shown. It is the policy of the growers' company to open the season with a low price for the purpose of encouraging consumption.

the growers put themselves in a position to gauge the factors which influence the sale of their product and are better prepared to take advantage of market conditions as they find them. Individually the growers were unable to do this.

6. The wide fluctuation in yields from year to year shows that the exchange has little or no control over the volume produced. Hence its energies are necessarily turned toward economies in marketing and stimulation of consumption. These are matters over which the growers acting as individuals can have but little control.

7. The cost of marketing cranberries has been reduced until now it is believed to be one of the lowest, if not the lowest, among the fruits. In 1920 the grower received 54 per cent of the consumer's dollar.

THE EVOLUTION OF MARKETING METHODS.

A national cooperative association was organized in 1907 for the purpose of uniting the cranberry growers of the country on a single method of disposing of their product. Cooperation among cranberry growers had its beginning prior to this time, however. Concerted action among growers in the sale of their berries had been carried on in both New Jersey and Massachusetts for some years.

EARLY COOPERATIVE SELLING ASSOCIATIONS.

In 1895 a number of the larger growers of New Jersey and Massachusetts organized and incorporated the Growers' Cranberry Co. This company employed the most expert cranberry salesman available at that time and opened an office in Philadelphia. Five per cent of the gross receipts was retained by the treasurer to cover all expenses, the remainder being returned each year to the growers in proportion to the value of their individual shipments.

Many of the growers had private brands, and the net receipts from each grower's shipments were returned to him. There was no pooling of returns. The advantage of having an efficient salesman who was in touch with market conditions controlling the distribution of even 25 per cent of the crop of the country became at once apparent.

The Cape Cod Cranberry Sales Co., composed of Massachusetts growers, was also organized about 1895 along the same general lines as the Growers' Cranberry Co. The Cape Cod growers were not so fortunate in their choice of salesman as was the Growers' Cranberry Co., and as a consequence their company was less successful.

The plan of operation of these two companies was not wholly cooperative as that term is defined today. The product of each member was sold separately, and returns were made to each member on the basis of the sale of his individual product. Berries were sold under the private brands of the individual growers rather than under a brand of the association. There was no coordination of sales between the two districts. Imperfect as was this form of cooperation, it was a great advance over no cooperation, and without question the experience gained by growers during this earlier period had much to do with their marketing successes of later years.

At the time these two growers' companies were operating the greater portion of the crop was sold by growers to cash buyers who traveled through the cranberry districts conducting separate negotiations with each grower. Some berries were marketed on a com-

mission basis also. These methods proved to be wholly unsatisfactory. The grower had no choice other than to accept the price offered, which in too many cases did not cover production costs. Furthermore, there were evidences which pointed toward collusion on the part of some of the buyers with a view to depressing prices. In 1902 there were 10 important car-lot cranberry shippers, and the severe competition among them often resulted in "cutthroat" practices.

It was the disastrous year of 1906 which actually brought about the formation of a central cooperative selling association, the National Fruit Exchange. Alliances among dealers were formed in that year for the purpose of attacking other dealers. Competition of a vicious sort was resorted to, some buyers offering the growers $5.50 a barrel [1] and quoting the trade $5. Rumors were afloat concerning the financial standing of the different buyers, and a general unhealthy condition was brought about. On top of the demoralized state of the trade came one of the largest crops that had been produced up to that time, and the country simply would not consume it. Prices fell as low as 70 cents a barrel, and carloads of berries were never shipped because they would not bring enough to pay freight charges. Notwithstanding these adverse conditions, such cooperation as existed among the members of the Growers' Cranberry Co., and the established reputation of their brands, enabled them to sell their 1906 crop at fair prices. One member of the company received an average of $6.51 a barrel net for his entire crop of over 8,000 barrels. All of the private concerns which handled berries that year lost heavily and were pessimistic regarding the future of the industry. In addition, there were prospects of a large increase in the production of cranberries. Newly planted bogs would soon come into bearing, and the growers realized that unless something was done the cranberry industry would soon be wiped out through lack of profits. If the country would not consume a normal crop on the acreage then in bearing, what would happen when this new acreage should begin yielding? This was the very real problem which faced the growers.

The figures in Table 1 show that the forecasts of increased production were correct. By 1909, just three years later, the crop had increased nearly 200,000 barrels.

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[1] 100 pounds net in one barrel.

TABLE 1.—*Cranberry production, 1909–1921.*[1]

[In barrels.]

Year.	Massachusetts.	New Jersey.[2]	Wisconsin.	Total.
1901–2	240,000	105,000	40,000	385,000
1902–3	215,000	30,000	46,000	291,000
1903–4	204,000	168,000	18,000	390,000
1904–5	256,000	83,000	21,000	360,000
1905–6	146,000	88,000	18,000	252,000
1906–7	240,000	103,000	45,000	388,000
1907–8	285,000	121,000	21,000	427,000
1908–9	233,000	75,000	12,000	320,000
1909–10	373,000	165,000	30,000	568,000
1910–11	287,000	241,000	16,000	544,000
1911–12	273,000	143,000	30,000	446,000
1912–13	300,000	112,000	45,000	457,000
1913–14	339,000	100,700	30,000	469,700
1914–15	450,000	155,000	33,000	638,000
1915–16	234,900	184,100	35,000	454,000
1916–17	337,700	168,500	38,000	544,200
1917–18	120,600	128,000	27,000	275,600
1918–19	195,000	126,700	30,000	351,700
1919–20	360,000	156,000	40,000	556,000
1920–21	277,000	130,000	33,000	440,000
Average	268,310	129,150	30,400	427,860

[1] These figures are based on freight records. Estimates of the Department of Agriculture extend only from 1912. The difference between the department figures and the figures of the American Cranberry Exchange from 1914 to 1920, here used, are not material.
[2] Includes Long Island production.

If this situation were to be remedied several things had to be done. In the first place, the growers themselves would in some way have to cooperate rather than compete in the marketing of the crops. They were unanimous in the opinion that cranberry production could not flourish on the basis of individual bargaining in the sale of the product. The disastrous, wasteful competition among the buyers must cease, for it had its direct effect upon the growers through the medium of ruinously low prices. And the demand for cranberries must in some way be made to keep up with the prospective increase in production. How these things were accomplished is in a large measure the story of an efficient marketing movement.

THE RISE OF NATIONAL COOPERATION.

A new epoch in the history of cooperative marketing among cranberry growers begins with the organization and operation of the Wisconsin Cranberry Sales Co. in 1906. This association was built on broader cooperative lines than were the New Jersey and Massachusetts companies.

The Wisconsin growers agreed to pool and market all their berries through this newly formed company. A private car-lot shipper was appointed as exclusive selling agent. Over 90 per cent of the growers of the State joined the company and it found immediate success.

The outstanding accomplishments of the members of this company in distributing their crop on the cooperative plan during the disas-

trous year of 1906 brought to the attention of the eastern growers a plan which they believed would aid materially in the solution of their marketing problems. Consequently the selling agent was asked to come East and explain to the growers of New Jersey and Massachusetts the plan of organization of the Wisconsin company. As a result, the New England Cranberry Sales Co. and the New Jersey Cranberry Sales Co. were formed in 1907, modeled after the organization in Wisconsin. Approximately 35 per cent of the growers in Massachusetts and 30 per cent of the growers in New Jersey joined the new associations.

These three State companies then formed a central selling organization, known as the National Fruit Exchange. This exchange was owned exclusively by the three State associations and operated by them on a nonprofit basis. Each company was represented on the board of directors according to the amount of acreage controlled by it, but no one company was allowed to have a majority of board members. Offices and distributing houses were opened in New York and Chicago, and store facilities were obtained in other large markets. The growers were assessed 7 per cent on the selling price of berries f. o. b. shipping point. Of this amount 2 per cent went to the State company and 5 per cent to the central selling organization for expenses. Money left over at the end of the season was refunded to the State association in proportion to the amount of business contributed.

During the next few years the National Fruit Exchange was in active competition with the Growers' Cranberry Co. It will be remembered that the latter company, although cooperative, did not have a pooling system and did not grade its fruit uniformly. Each grower's fruit was marketed separately at his own risk. The large crop of 1910, together with the losses incident to price cutting between two strong growers' organizations in active competition, led to the consolidation in 1911 of the Growers' Cranberry Co. with the National Fruit Exchange to form the present American Cranberry Exchange. The New Jersey Cranberry Sales Co. went out of existence and the Growers' Cranberry Co. took its place in the central organization. This consolidation increased the membership of the exchange about 20 per cent.

In 1919 each company reorganized and formed a nonstock, nonprofit, cooperative organization in order to comply with the Clayton amendment of the Sherman antitrust law. However, no change was made in the marketing methods or operation and the former pooling and grading systems were retained. At the present time, the exchange controls about 75 per cent of the total crop in Wisconsin, and about 65 per cent in both New Jersey and Massachusetts.

TABLE 2.—*Volume of business handled by the exchange since its organization in 1907.*

Year.	Shipments.	Value.	Average price per barrel.
	Barrels.		
1907–8	143,646	$909,542	$6.33
1908–9	110,274	863,847	7.83
1909–10	207,014	1,066,947	5.15
1910–11	188,062	1,058,903	5.63
1911–12	235,696	1,680,302	7.13
1912–13	259,254	1,710,403	6.60
1913–14	278,670	1,797,809	6.45
1914–15	323,173	1,284,163	3.97
1915–16	259,780	1,642,708	6.32
1916–17	279,476	1,828,900	6.54
1917–18	154,812	1,608,847	10.39
1918–19	209,666	1,863,244	8.89
1919–20	321,374	2,526,153	7.86
1920–21	284,019	2,935,818	10.34
Average	232,494	$1,626,970	$7.00

THE AMERICAN CRANBERRY EXCHANGE.

The American Cranberry Exchange is a membership organization composed of cranberry growers who are also members of one of the three State companies. It functions merely as a selling agency for its members. To explain the organization, it is necessary to explain the makeup of the State associations. The New England Cranberry Sales Co. is the largest of the State units and may be used as an example of the form of organization.

The New England Cranberry Sales Co. was incorporated originally in Massachusetts in 1907 and reincorporated in the same State in 1919. It is a nonstock and nonprofit growers' cooperative organization with its principal office at Middleboro, Mass.

The membership of the company consists of "persons, firms, associations, or corporations engaged in the business of growing, packing, or shipping cranberries or their by-products." To become a member, a written application must be made to the board of directors and must be approved by two-thirds of the directors present and voting. A membership fee of $20 is collected, half of which goes to the State association and half to the central organization. The dues are $1 a year. Each member is entitled to one vote. The State associations do not have specific membership contracts. However, "each member, until he ceases to be such, agrees to deliver and ship his entire cranberry crop under the rules and regulations of the company." In most cases it is recommended that members be required to sign contracts in addition to signing the by-laws.

The officers of the company consist of 33 directors, a president, first and second vice president, treasurer, and clerk. The board of directors must be elected from among the members of the company.

The directors have the duty, authority, and full power to perform, or authorize to be performed, all acts which in their judgment are necessary in promoting, protecting,

or advancing the prosperity and business interests of the company or the object for which it was organized, limited only by the laws of the Commonwealth or by the charter or by-laws of the company explicitly reserved to the members.

Members may, by a two-thirds vote of those present and voting, at any annual meeting or other meeting called for that purpose, authorize the directors to levy an assessment, not exceeding a definite amount per barrel, or its equivalent, on cranberries marketed; the proceeds to be spent for advertising or other special services relating thereto, but for no other purpose; the assessment to be deducted from the proceeds of sales.

The expenditure for advertising amounted to 27½ cents a barrel for the year 1920–21.

The directors are also empowered to determine the percentage of the proceeds of sales to be retained for selling and operating expenses and the maintenance of the operating fund, which percentage, it is estimated, should not exceed 7 per cent.

The companies have no capital stock. The State companies are allotted 2 per cent, deducted from sales f. o. b. shipping point, to cover operating expenses, while the central organization is allotted 5 per cent. In Massachusetts a reserve fund is maintained which consists of the unexpended balance of the 2 per cent allotment together with the company's share of the unexpended balance of the 5 per cent allotment to the central association. These unexpended balances are kept in the hands of the company for one or more years before they are returned to the growers in the form of sales expense refund. A small reserve of from $1,000 to $5,000 is maintained by the Wisconsin company on the same basis.

In New Jersey a revolving fund is maintained by means of loans from members. The initial loans are repaid in five equal annual installments and all subsequent loans run for 5 years without interest. The Massachusetts company has a similar arrangement, with the exception that the loans run for 10 years instead of 5. Since the loans are made by members in proportion to their volume of patronage, each member contributes a share to the revolving fund equal to the benefits he receives from the association.

During the year 1920 the New England Cranberry Sales Co. borrowed over $400,000, which was used to make partial payment to members for cranberries of standard brands shipped. These loans are made upon receipt from the shippers of the bills of lading. These advance partial payments have varied from $3 to $5 a barrel, depending upon the market price of the berries. The Growers' Cranberry Co. of New Jersey advanced over $100,000 to members in a similar manner.

In this way the members, through group action, perform a financing as well as a marketing function. The collective credit of the group makes necessary funds available to the individual growers.

The membership in the various companies is approximately as follows: Massachusetts 350, New Jersey 115, and Wisconsin 43, making a total of 508. In many cases a membership consists of a company rather than an individual. Consequently the number of members is not an indication of the size or importance of the association when comparing it with other growers' organizations. A single company holding only one membership may grow and ship through the association more than 75 cars of berries in a single year.

The growing of cranberries requires, relatively speaking, large amounts of capital. It is not unusual for the cost of developing a bog to exceed $750 per acre. Furthermore, picking, sorting, and packing charges ordinarily run from $100 to $300 per acre for a single year.

TABLE 3.—*Cost of handling cranberries from the bog to the car at local shipping point, 1920.*[1]

State.	Number of barrels included in cost records	Total cost.	Cost per barrel.
Massachusetts	41,612	$119,120.36	$2.86
New Jersey	16,401	70,531.11	4.30
Wisconsin	4,936	18,187.54	3.68
Total	62,949	207,839.01	.....
Average	.....	.....	[2] 3.35

[1] This cost includes picking, sorting, packing, storing, and carting. Expenses of growing and the interest and depreciation on capital and equipment involved in handling the crop from bog to car are not included. The figures are based on costs to a number of representative growers in the three districts.

[2] This average is obtained by weighting the cost per barrel in each State with the volume of cranberries shipped by the association from that State.

The Massachusetts association operated four houses during the season of 1920 for the cleaning and sorting of the berries of members at cost. The operating expenses of these houses averaged 54 cents a barrel for cleaning, packing, sorting, and overhead expenses. This figure does not include the cost of picking, containers, storage, or cartage.

The amount of capital required in the growing of cranberries explains the tendency toward group action in the production of this fruit.

The organization of the American Cranberry Exchange is very similar to that of the State companies; the main difference is that it has only 13 directors. The members are elected in the same manner as in the State companies. The members in the three State companies elect delegates to the annual meeting of the American Cranberry Exchange, who are elected directors of the exchange at the meeting, most of the members voting by proxy. Massachusetts supplies 6 directors, New Jersey 5, and Wisconsin 2. No one State is allowed a majority on the board of directors.

IMPROVEMENTS RESULTING FROM COOPERATION.

The improvements of marketing methods have been brought about through developments along five rather distinct lines. The first and basic improvement was that of raising the quality of the fruit reaching the consumer by means of close grading and careful packing. Next pooling systems were adopted which equalized prices to growers for the same grade of product. These two procedures were fundamental and upon them the associations were able to build constructive policies looking toward the stabilization of the market and the extension of the demand for their product.

In addition to improvements in the way of equitable pools, better grading, standardizing, and packing, the cranberry growers have also amply demonstrated the possibility of great market improvement by means of better correlation of demand with existing supply. This improvement has been brought about in three ways: (1) By securing the good will of the consuming public through advertising; (2) by cultivating the good will of the jobbing and retail trade through stabilizing the market; (3) by carefully estimating the potential supply of cranberries to be sold, together with the probable demand, and then attempting to place an opening price upon the product at a rate that will induce the consumption of the existing supply.

GRADING.

In the matter of grading, the cranberry industry has developed along lines different from those obtaining among most other perishables. Early in the history of the industry individual growers established brands, defined them in loosely approximate terms, and sold by these brands to the trade. The problem of the exchange was to standardize these brands in such a way that they would form a reliable medium for buying and selling between grower and wholesaler and a sound basis for advertising. Something like 80 brands designating quality, State where grown, and variety are known to the wholesale trade. However, cranberries reach the ultimate consumer under one name only—the association's good-will emblem. Under this one brand the association in effect notifies the consumer that it assumes the responsibility for the quality of the berries sold under this name.

At the time of the organization of the selling agency in 1907, the trade was confused by a multitude of loosely defined brands, many of which were only slightly known. This limited knowledge on the part of the trade made it extremely difficult to sell berries in any markets except those where a particular brand was known. It is practically impossible to sell berries in any way except by brand, because the markets in the United States vary widely as to the type of berry desired. New Jersey berries do not sell well in New York but are

very popular in the Middle West. New York City prefers a dark-colored berry, while Pittsburgh, St. Louis, and many western markets prefer the lighter-colored fruit as the darker fruit is considered by them overripe.

In order that national distribution might be accomplished, such as the exchange contemplated, it was necessary that standardized grades be established and that these grades be designated by widely-known brands. The adoption of company brands at first restrained a number of the largest growers from joining the cooperative associations, because of their objection to surrendering the individual brands under which they had been selling fruit for many years. However, most of these growers later joined and are now loyal supporters of the exchange.

There are several principal varieties of berries grown in the three States. These varieties are classified according to size, color, and shipping quality. The latter is taken into consideration because berries which are of the same variety and color often differ as to shipping quality. The shipping quality is usually determined entirely by experience and personal judgment. To take care of these numerous differences, it was found necessary to establish some 80 different brands. This allows a buyer to order the exact type of berry he wishes merely by designating the brand.

The associations employ a number of district field agents who regularly visit the growers in their own districts during the packing period to inspect the crop and insure proper grading and packing, to collect information as to the quality and quantity of the crop, to keep the members informed as to the trend of markets, to arrange for shipments, and to be of service to the members and their sales agency.

POOLING.

Another change brought about through cooperation was the establishment of pooling systems, an innovation in the cranberry industry. Previously, companies which had been formed for the marketing of berries had sold on a commission basis, remitting to the grower the price which his particular berries had brought, minus the commission.

The manager of the newly organized selling agency believed, however, that centralized selling control was a necessity, if success were to be attained. In order that centralized selling control might be established, it was necessary to adopt some system that would eliminate the possibility of unfair distribution of high or low priced orders among the members. In addition, it was necessary to equalize transit risks and market fluctuations after the berries were out of the growers' control. The pooling system was adopted as answering these purposes.

The pooling system established on Cape Cod was different from that in New Jersey. In Massachusetts only one pool exists for each principal variety for the season. The grower is required to ship his berries whenever he is told to do so, and receives the average price of the season obtained on the fruit shipped. If he is required to hold his berries longer than a stated time, he is paid premiums to reimburse him for the normal shrinkage of the berries while in his possession, this premium becoming greater the longer the berries are held. The amount of the premium is decided by the members at the beginning of each season.

In New Jersey the seasonal pool does not exist. There they have weekly pools and the grower may ship in any week he chooses. The difference in the pooling systems of the two companies is caused primarily by the preponderance of small shippers in New Jersey who want to choose their own time for selling. Owing to their small individual crops, they can store their berries for some time without inconvenience. The pooling system in Wisconsin follows very closely that of Cape Cod and includes only one pool a year.

Without question the grading and pooling systems instituted by the exchange have contributed in a large measure to the success of the undertaking.

ADVERTISING.

The good will of the consuming public is a valuable asset in any attempt to increase the consumption of a specific commodity. If the cranberry growers were to receive the cost of production for their fruit it was necessary that consumption be increased. Hence the exchange turned to advertising as a means of creating a favorable attitude in the minds of the public toward the cranberry as a food product. It should be emphasized that by means of improved grading and packing, which resulted in a higher quality of fruit reaching the consumer, the associations had already gone a long way in cultivating the good will of the consumer. Had not the associations raised their quality to a high standard through careful grading and packing, it is doubtful whether advertising could have been carried on successfully, since it is generally agreed that effective advertising of a food commodity requires uniform quality. For instance, when the consumer is induced by advertising to use a certain commodity of pleasing quality, the effect of the advertising is lost as soon as the quality becomes displeasing. If the public asks repeatedly for a certain branded article it is because the quality represented by the brand has proved satisfactory in the past. Hence it is of the highest importance that quality be consistently maintained. It does not follow that only high quality can be advertised with success. The consumer and the trade must know, however, that they are receiving the same quality under a given brand that they have received in the past under the same

brand. In the case of the cranberry growers, it can be safely said that the basis of their advertising efforts was the establishment of standardized brands and packages.

In 1906 the country would not consume the heavy crop of cranberries at anything like a price approaching production costs. Furthermore, at that time there was every indication that production would increase. Production did increase from 388,000 barrels in 1906 to 544,000 barrels in 1916. At the same time that the increase in supply threatened to demoralize selling prices, the cost of production was continually rising. In 1919, it is estimated that the average cost of producing a barrel of cranberries was somewhat more than the average selling price for the years 1907–1917.

In the face of these rising costs, in 1916 the growers through their organization decided that increased consumption was the only way out. To this end a trial advertising campaign was inaugurated in Chicago in an attempt to find out just what advertising would do for the consumption of cranberries. About $23,000 (not a large amount as advertising sums go) was spent that year in Chicago in newspapers, street cars, printed bulletins, and service work.

TABLE 4.—*Comparison of sales in 1916 with those in 1913, 1914, and 1915 in six leading markets.*

Market.	Gain or loss in 1916 over—		
	1913	1914	1915
	Per cent.	*Per cent.*	*Per cent.*
Chicago	+57	+27½	+47½
New York	− 2	−18	+ 5
Boston	−36	−12	−50
Philadelphia	−41	−57	−17
Pittsburgh	−13	−18	− 1
Buffalo	−11	− 7	− 8
Cleveland	−22	−10	− 8

In the table it will be noticed that the Chicago sales for 1916 show a decided increase over the sales of the three preceding years, while the other markets with but one exception show a loss.

This test campaign indicated that advertising increased consumption, and it was decided to continue the practice on a larger scale. In 1917 an advertising assessment was made, but the campaign was abandoned because the crop was cut in half by a September freeze.

In 1918 the first national advertising campaign was inaugurated and $54,000 was spent in about 30 days, beginning about October 15 in the United States and October 6 in Canada. The market outlook was indeed black. Sugar distribution was restricted by the Federal Government to 2 pounds per capita per month, whereas the normal consumption is 4½ pounds per capita per month. The weather was warm. The trade in general was apathetic and the universal opinion

was that cranberries would have a very slow and moderate sale no matter what price was asked. But largely as the result of advertising and efficient marketing methods, cranberries had an unusually successful season. The price mounted steadily from the middle of November to the last week in December, when it reached $22 a barrel.

The advertisements were along educational lines. Much emphasis was placed upon methods of serving the fruit in such a way as to arouse and please the appetite. Because of the sugar shortage, attention was also given to methods of cooking the cranberry with much less than the usual amount of sugar.

The following are a few expressions received by the exchange from the same agents and customers in widely scattered markets just before and just after the advertising campaign:

BEFORE.	AFTER.
A. Broker.—October 26: "Refuse confirmation. Deaf, dumb, and blind to cranberries."	A. Sold six cars in November.
B. Broker.—October 24: "We can not encourage any shipments in here until there is a better demand. Still have about 80 barrels of the last car Mayflower on hand."	B. Sold 12 cars in November. November 20: "The trade has waked up here in the last 24 hours and now seems to want its cranberries delivered at once. We congratulate you on the way you have handled the situation."
C. Broker.—October 24: "Cranberries are moving very slowly. I should be able to sell the car you wish to ship Friday but to be frank it will be a hard job."	C. Sold seven cars in November and could have sold many more. November 29: "This mode of procedure is like frenzied finance, and it makes me dizzy to keep up. I hardly know where I stand, only I must have another car or two shortly and will look to you to get some for me."
D. Broker.—October 25: "The jobbers seem to have it in their heads that cranberries are not going to sell here to any great extent."	D. December 4: "Jobbers all out of cranberries. Can't you possibly divert or ship car? Would like to get enough to make a minimum car from Chicago. Want them to cost not more than $17.40 delivered."
E. Broker.—October 25: "Our customers are badly stuck with early blacks; one still has over 100 barrels on hand because there is absolutely no sale for cranberries at present."	E. November 27: "I find everybody demands their full share of berries; therefore I am in a pinch. I can not fill all my orders even if the next car contains 240 barrels. Of course I will be obliged to cut some of my customers down and they will squeal, because the demand has been very large and so much better than we expected."

It is the belief of those in authority that if no advertising had been done during the year the crop would have netted less than $6 a barrel, which was not considered a profitable price to the grower.

As it was, however, an average price of $8.89 a barrel was obtained, resulting in an estimated gain of over $1,000,000 to the growers.

Conditions in 1919 were worse than ever before. There was a very large crop (556,000 barrels), the third largest in the history of the industry. The sugar situation instead of improving was becoming worse. Transportation facilities were demoralized and weather conditions were adverse. The opening price for cranberries was placed at $8.50 a barrel. In the last week of September severe sugar restrictions were placed on the country and the price of sugar rose to 25 and 30 cents a pound retail. The price of cranberries fell to $7.50 by the middle of October. Approximately $123,580 was spent in advertising that year. Toward the last of October results began to be felt, and by the middle of November the price again reached $8.50.

For the year 1920 there was an allotment of approximately $108,000 for advertising purposes. Of this amount, $77,937 was expended on advertising, which was an amount equal to 27½ cents a barrel on the total sales of the season. Nearly $31,000 of the advertising assessment was returned to the growers, because the demand was sufficient to clean up the supply without further advertising expenditure.

Up to and including the season of 1920–21 a total of $293,434 was spent for advertising purposes. This amount is equal to an average of 20 cents a barrel on all cranberries shipped cooperatively from 1916 to 1921.

It will be noticed from the data contained in Figure 4 that more money was received for a small crop in 1917 than was received for a crop over twice as large in 1914. Since 1917 the amount of money received has been more nearly in proportion to production. That is, a large crop has not necessarily meant small total receipts.

It might be inferred that the increased receipts from cranberry sales were due to the general wave of rising prices. But this can hardly be the case, for the price and scarcity of sugar had a tendency to depress cranberry prices. This tendency was combated by the stimulation of consumption through advertising. Furthermore, if the increase were due in any large measure to the forces that caused prices to rise during the war, it would naturally follow that cranberries would fall in price during 1920–21 in the face of an average crop and in a period of falling prices, but this was not the case.

The bad years test to the fullest extent the advantages of cooperation. In all probability had it not been for advertising and the ability of the exchange to distribute shipments in a way to establish and maintain a reasonably stable market, many carloads would not have been sold at all in 1919, and the rest would have been sold

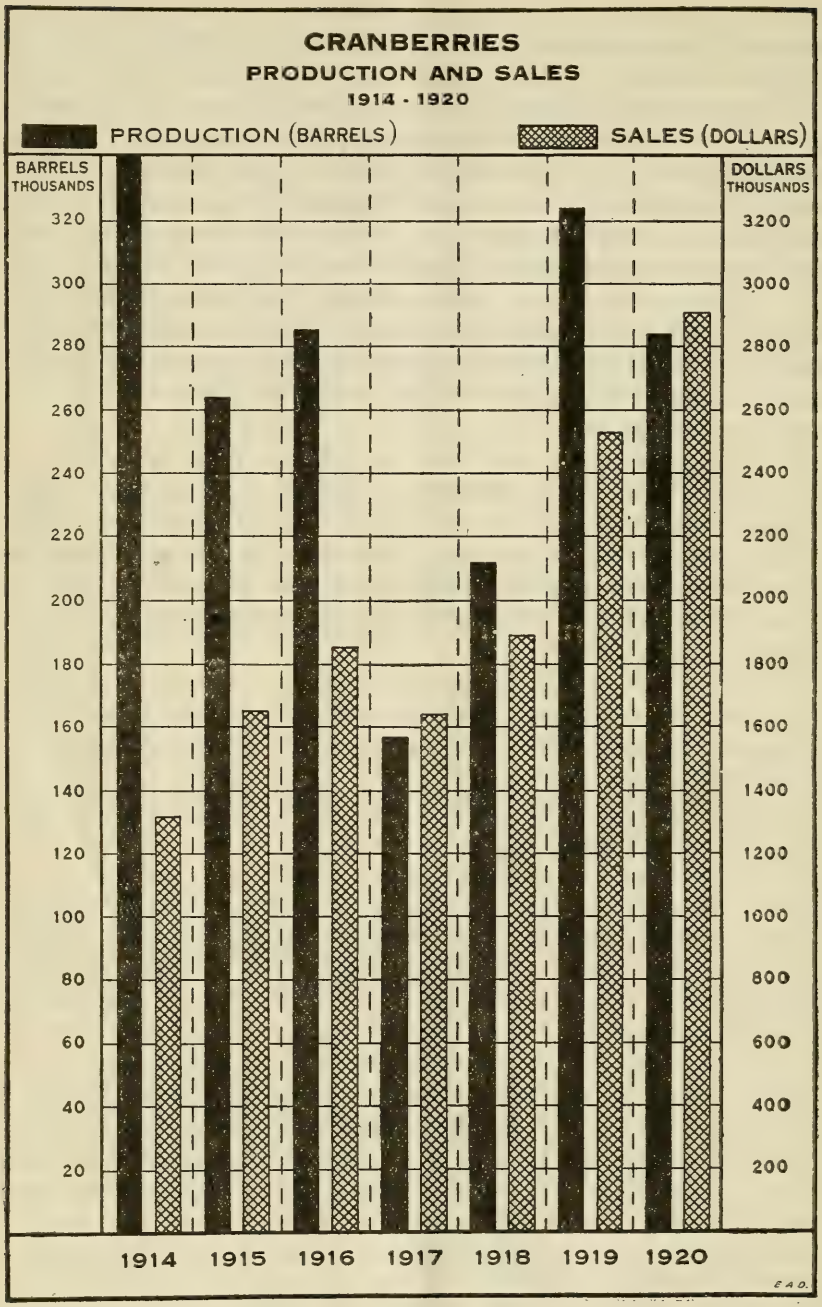

FIG. 4.—Before advertising was begun it was not unusual for a large crop of cranberries to bring a smaller total receipt than a small crop. The crop of 1914 brought less than a crop one-half as large in 1917. Advertising was begun in 1916. Even in the face of sugar shortages and increased transportation rates, growers' receipts have not decreased with increased production since that date.

for prices which would have meant a decided loss for all those interested in cranberry production.

This view is expressed by the general manager of the American Cranberry Exchange in his annual report for the season:

> When we consider that the cost of production of a perishable food that is not a prime necessity—a crop which must be sold while it is sound and in season—has practically no influence on the sale price, the comparative proceeds obtained for this crop, notwithstanding the serious sugar shortage and the intermittent and difficult transportation conditions, seem to me to prove conclusively that a great saving of waste and values was secured through cooperative distribution and advertising.

Figure 5 shows the per capita consumption, by States, of cranberries shipped through cooperative organizations. It will be

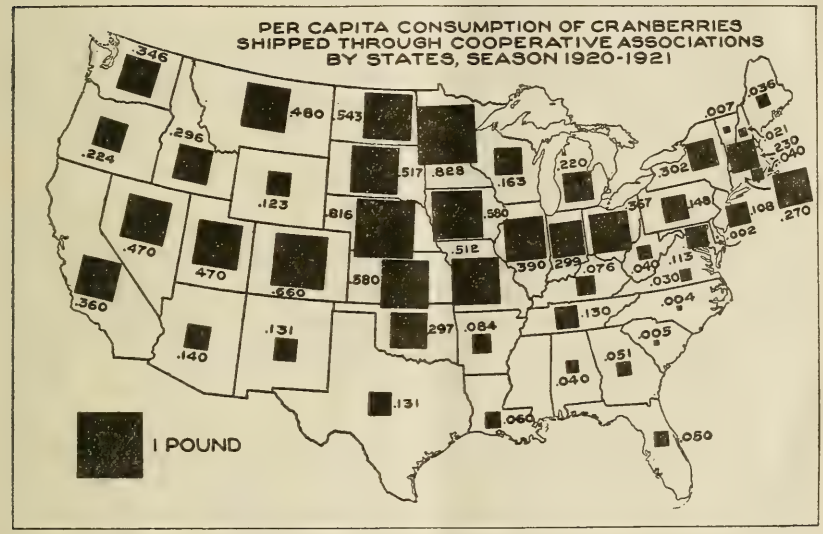

FIG. 5.—There are immense possibilities in the way of increasing the consumption of cranberries. The average per capita consumption in the United States for the season 1920–21, based on the cranberries shipped through the exchange, is slightly over one-fourth of a pound. Since the exchange handled approximately 65 per cent of the total production, the total per capita consumption was less than one-half pound. Surely a per capita consumption of one pound of cranberries yearly is a conservative possibility. A realization of this possibility would mean over twice the present average yearly production.

noticed that Minnesota has the highest record with a little over 0.8 pound per person. This low consumption rate indicates that many people, even in the States of highest per capita consumption, eat no cranberries whatever. Hence the great possibilities of increasing consumption is readily appreciated. Advertising is one of the mediums through which this possibility may be realized.

COOPERATION WITH THE TRADE.

Since the association markets its product through regular wholesale and retail channels, the good will of the trade is a vital asset. It must be admitted that the dealers (jobbers, retailers, and their

salesmen) can do much in the way of pushing the sale of a product through proper display and through good sales methods and suggestions. The exchange adopted the policy that the interest of the dealers in their fruit could best be obtained by the establishment of stable market conditions, thus insuring them a reasonable profit.

It is believed furthermore that a stable market lessens distribution costs. It is held by the association that "the smallest liability to loss and the greatest certainty of a moderate profit interests dealers more quickly and certainly than the possibility of large profits, coupled with the danger of serious loss." One of the reasons for what seems to be exorbitant profits charged by dealers for the handling of fresh fruits is occasioned by the danger of loss through violent fluctuations of market prices.

To avoid these fluctuations in the cranberry market, the exchange has attempted to regulate distribution in such a way as to eliminate the "glutted" and "famine" markets which were so disastrous to all concerned, including the consumer.

COORDINATING DEMAND WITH SUPPLY.

Successful marketing consists largely of accurately gauging the factors of supply and accurately estimating the factors of demand with a view of anticipating the price which will coordinate these two sets of forces. For instance, if the association should ask too low a price for its fruit it would not have enough to supply the demand. If it should ask too high a price the entire crop would not be sold by the end of the season.

This principle may be illustrated further. In 1912 the following questionnaire was sent to 200 retail dealers throughout the United States: "Suppose the retail price of cranberries is 8⅓ cents per quart, or 3 quarts for 25 cents. Please state what reduction in your sales would result from advancing the price to 10 cents per quart, 12½ cents per quart, 15 cents, and 20 cents." Ninety-two replies from 20 markets located in 16 States were received. The average estimated percentage of decrease of sales as price advanced was as follows:

An advance of 8⅓ cents to 10 cents per quart reduces sales 12 per cent.
An advance of 10 cents to 12½ cents per quart reduces sales 23 per cent.
An advance of 12½ cents to 15 cents per quart reduces sales 37 per cent.
An advance of 15 cents to 20 cents per quart reduces sales 67 per cent.

Although the price levels of 1912 have little relationship with the price levels of to-day, it is probable that proportional increases in present price levels would have similar effects upon consumption.

The economic value of the cranberry is represented by the highest price (or series of prices) that will clean up the supply by the end of the normal selling season. It is to the advantage of the association

to obtain as high a price as possible, but in obtaining this price care must be exercised that future consumption is sufficiently encouraged to take care of the normal season's yield.

With these points in mind it can be seen that the success of the association depends not so much upon influencing the market as on putting itself in position to gauge the factors which influence the sale of its product. Thus it can be prepared to take advantage of the conditions which exist.

The only price named by the exchange is the "opening price" at the beginning of the season. Market conditions set the remaining quotations. Experience has proved that it is of the utmost importance that this opening price conform closely to supply and demand factors. As an illustration, in 1920 the exchange's opening price was $8.50 a barrel, while private dealers were quoting $10 a barrel. Much complaint came from the competing trade because of the exchange's low price. Yet the manager and directors of the association were convinced that market conditions would not permit a retail price higher than 15 cents per quart. An exchange price higher than $8.50 per barrel would not allow a 15 cent retail price. The slow demand at the beginning of the season proved the wisdom of not setting a higher price. Cancellation of conditional orders equaled 30 per cent, when ordinarily it does not exceed 10 per cent. One of the strongest markets canceled 7 out of 10 orders. Certainly a higher opening price would have proved disastrous by discouraging consumption. That the price was not too high is shown by the fact that cranberries began to advance shortly after the beginning of the season and continued to increase until all berries were sold. Figures 2 and 3 show that cranberry prices increased during the 1920 selling season while the prices of other commodities decreased at a rapid rate.

The importance which the association places on the influence of an opening price may be gained from a statement of the general manager of the exchange in a report to the members of one of the State associations: "I am positively convinced that the greatest, most common, and most fatal of errors committed by marketing organizations and shippers is made in establishing their starting or opening price."

It goes without saying that naming a price which will coordinate demand with the existing supply requires the exercise of sound judgment based upon long experience in the marketing of the product in question. Here, then, is another advantage inherent in sound cooperative organization. Individually the growers are not able to avail themselves of this talent and experience. Collectively they are able to employ as efficient guidance as that with which they must compete in the sale of their product.

IMPRACTICABILITY OF PRICE CONTROL.

At the present time the public entertains a vague fear that the farmer may gain control over price by the exercise of monopoly power through his cooperative marketing associations. Monopolization of the supply of any "freely produced" goods is a task that has never been accomplished for other than temporary periods. Agricultural products are "freely produced"; that is, the important farm products are grown over wide areas. Their production is not confined to any one State, one nation, or one continent.

The cranberry, for instance, requires a most highly specialized combination of soil and moisture requirements—land that can be flooded and drained at will. Because of the necessity of this highly specialized cultural environment it is looked upon as a restricted crop, one of the least freely produced among the agricultural products. Yet the area which can be devoted to cranberries is subject to great expansion should the price of the fruit be such as to encourage the production of a greater supply. This country has a goodly supply of swamp lands suitable for cranberry culture, which would be brought under cultivation if the price of cranberries should encourage an increased supply. To maintain an abnormally high price and at the same time to restrict production, it would be necessary for the present growers to control all the potentially available cranberry lands—a practical impossibility.

Because farm products can be grown over such wide areas, the monopoly of the supply of these products would require an organization of national scope. The whole-milk supply of the cities is about the only important exception to this generalization. Because of the perishability of this commodity its production is confined to rather restricted areas near the place of consumption. Yet it is doubtful, indeed, whether producers of whole milk can be successful in any large measure in the marketing of their products if their methods depend upon monopoly power. Monopoly power in the marketing of agricultural products, even in goods produced in restricted areas, such as whole milk, defeats its own end. This defeat comes about by reason of the fact that a higher than a competitive price encourages overproduction to an extent that the farmers' organization becomes wholly unable to dispose of the excessive supply at a price sufficient to maintain this increased production. Since monopoly price presupposes the control of supply, it places the monopolization of farm products practically beyond human accomplishment. It is quite conceivable—although practically impossible—that the number of acres planted could be regulated through organizations or otherwise, but the amount that will be produced from this acreage for any given year is a matter of conjecture at the time of plant-

ing. An exceedingly favorable year will increase the expected yield 25 per cent. On the other hand, floods, droughts, disease, or insect pests may reduce the expected returns to as great an extent.

Furthermore, in connection with the possibility of controlling the supply, it should be remembered that farm products for the most part, because of their perishable nature, must be "cleaned up" each year. It is not easy to carry them over from season to season in an effort to restrict the supply going on the market during any one season. It is sometimes suggested that growers may leave their products unharvested in order to restrict supply and at the same time reap a higher price for the reduced supply than would have been received for the whole. This suggestion might appeal to the grower were it not for the fact that he has expended much money, time, and effort in bringing his product to the harvest period, and the loss of this expenditure for one year would in most cases burden the next year's crop with a loss not likely to be repaid. In fact, he has no assurance that next year's crop can carry its own burdens. There are times when crops are not harvested, but such a condition is due, not to the desire of the grower to restrict production, but to the fact that the market price will not pay harvesting and marketing costs.

It should be remembered that monopoly among farmers requires the united action of a large number of individuals, which makes secrecy impossible, and hence exposes any artificial price control to the law and to the public. The human element presents a serious obstacle in any attempt to enforce the sufficient unity of action necessary to create monopoly power among a large number of individuals scattered over wide areas.

So much for the power of farmers controlling the price of agricultural products in general. Are the cranberry growers' organizations an exception to the above principles?

Since the organized growers control approximately 65 per cent of the cranberry supply, it might be concluded on first thought that they are in position to control arbitrarily the price of their product. A brief analysis, however, will show that artificial price control is nearly impossible. It must be accepted as a fact that the forces which influence supply and demand are the forces which influence price. The cranberry growers, therefore, in order to control the price must exercise a direct influence over the forces which regulate the production of the berries, as well as control the forces which tend to govern the buying tendencies of the consumer.

First, let us examine the supply side of the equation. In general, the size of the cranberry crop depends upon the number of acres in bearing and the yield per acre. The cooperative associations do not attempt to influence the number of acres devoted to cranberry

culture. It is doubtful, indeed, if the association could influence acreage to any great extent. If cranberry production yields a good return over a period of years, the acreage devoted to this product increases as a matter of course. If, on the other hand, returns are small, acreage decreases. Hence the exchange influences acreage only indirectly through the relation of the price obtained to the cost of production. Certainly it has no power to say who shall or who shall not grow cranberries. Furthermore, since cranberries do not come into full bearing for four to six years after planting, a program of artificial restriction of acreage would have the added difficulty imposed by the necessity of forecasting conditions likely to exist four to six years in the future.

In regard to the yield per acre, it can be safely said that it is the earnest desire of the cooperative associations, as well as that of every cranberry grower, to attain the highest possible efficiency in production. Efficiency in production demands yields commensurate with the amount of land, labor, and capital devoted to the enterprise. Cooperative associations materially aid the growers to increase their efficiency in production by the adoption of improved methods and practices. To this end specialists on cranberry culture are employed to visit and advise with the growers.

The futility of control of the supply by the association is better illustrated by the fact that weather conditions and disease and insect pests beyond the control of the grower, may double, cut in half, or practically wipe out altogether the yield of a given district.

The fluctuation in yields since the organization of the growers in 1907 is an indication that the associations have little control over quantities produced. During the last 14 years cranberry production has fluctuated from 40 per cent below the average to 35 per cent above the average. (See fig. 6.) The cooperative associations own no bogs. As has been stated, to monopolize supply would require that they own or control all potential cranberry acreage—an almost impossible accomplishment. In short, the possibility of artificially regulating the quantity of cranberries grown during a given season seems at present beyond serious consideration.

Prices are as dependent upon conditions influencing demand as they are upon the factors of supply. Especially is this true of commodities which are easily substituted or not considered as necessities, a class which includes many fruits and vegetables. The whims of the consuming public may make such a commodity valuable or worthless regardless of its production costs. This is a fact overlooked in too many instances. It can be said without hesitation that the price received for cranberries is dependent in no small measure upon the demand of the consuming public.

What are the more important factors making up the demand for cranberries and how can they be influenced? Demand is influenced in a large measure by weather conditions during the selling season (cool, crisp weather is conducive to increased consumption); the supply of other fruits which may readily be purchased in place of cranberries; the supply and price of sugar—a primary consideration; the ability of the consumer to purchase, as reflected by the prosperity of the people in general; the good-will attitude of the trade and the public toward the fruit.

Certainly growers, neither individual nor organized, can hope to exercise control over the weather conditions during the selling season,

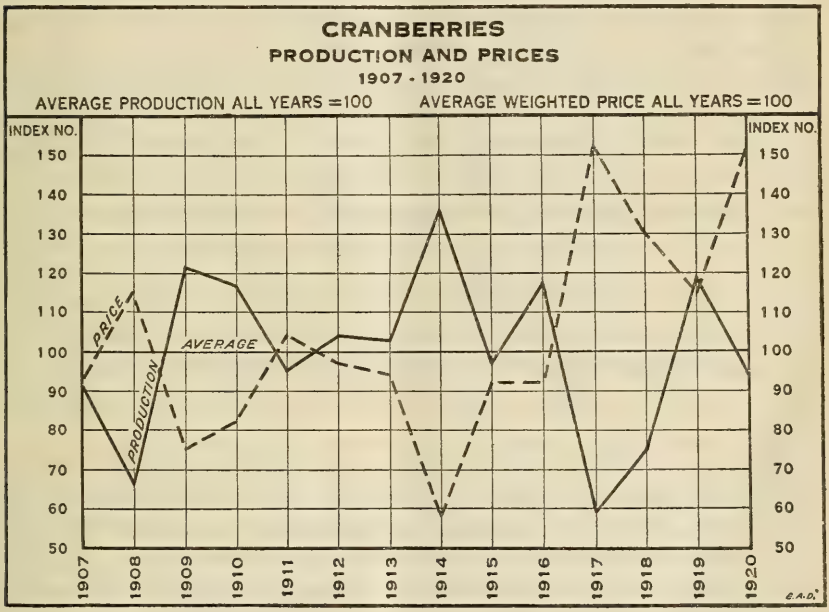

FIG. 6.—The wide fluctuation in cranberry production indicates that the cooperative associations exercise little or no control over quantities produced. During the two seasons just past, the price has not decreased in the same degree that production has increased. A 95 per cent crop brought a price ranging from 15 to 50 per cent above the average.

the supply of competing fruits, the price of sugar, or the prosperity of the consuming public. Hence it requires no argument to point out that the growers' associations have no monopolistic grasp on prices by reason of their control over the factors of demand. The associations do attempt to secure the good will of the dealers handling their product and also the good will of the public consuming it, which are worthy objects.

The good will of the consuming public is the most valuable asset the cranberry growers can possess as an aid to the successful marketing of their fruit. This good will must be secured and retained. It is for this reason that an unduly high price on cranberries is a matter

of equally grave concern to the association as an unduly low price. The grower has learned by experience that his best interest requires the custom of the great bulk of the consuming public—laborers and farmers. He has also learned that a retail price above 25 cents a pound cuts off this class of consumption. When to these two accepted facts is added the further knowledge on the part of the growers' association that the custom lost when the fruit goes above 25 cents a pound retail is difficult to win back, it can readily be seen that it is not to the growers' best interests that fruit should be sold at high prices. Careful marketing studies have shown the growers that an association price to the wholesale trade above 15 cents a pound is likely to result in a retail price above 25 cents. Hence, it is to the advantage of the association to place the bulk of its supply on the market at a price below the 15-cent mark.

The 1921–22 season illustrates this point. The crop was short. The demand for berries was good. If the association had distributed its supply during the normal selling period, the demand for berries would have caused the price to advance early in the season to a level that would have cut off a large class of people whose custom is valuable during a season of normal production. In order to avoid this, the association kept pushing its berries on the market in order to satisfy the demand at rates that would permit a retail price of 25 cents or less. As a result of this policy, the association's supply was practically exhausted before the end of December, whereas in a normal year the selling season continues until the latter part of February.

Here is a concrete instance of a cooperative association throwing its supply upon the market to discourage unduly high prices. This action was in keeping with the best interests of the association as demonstrated by past experience. It was in line with a long-time sales policy designed to retain the volume of custom necessary to the disposal of a normal crop.

When the good will of the consumer is such a dominant factor in the sucess of a marketing organization, it can hardly be said that the organization is in position to exert an artificial control over the price of its product.

THE EXPENSE OF MARKETING CRANBERRIES.

Cranberries are handled by the grower up to the time they are placed in the car for shipment. Picking, sorting, carting, packing, and a greater part of the storage is performed by the grower and is considered a part of his production cost. The local associations, however, supervise the performance of some of these practices. In Massachusetts the cooperative association operates four screen houses where farmers may have their berries screened, sorted, and packed at cost.

LOCAL ASSOCIATIONS.

The marketing expense begins with the local association. The grower has his direct dealings with the local association and it acts as an intermediary between him and the central selling organization. It maintains an office in the cranberry district where all records of shipments and sales are kept for the growers' inspection. The local associations employ field agents whose duty it is to see that all picking, packing, and grading practices are conducted in the proper manner. The local associations also furnish barrel and box labels to the grower and whatever advertising is placed in the packages. They order the cars, thus relieving the grower from all dealings with the transportation companies. They distribute the orders received from the central selling organization and take complete charge of the pooling system. They distribute to the individual growers the money received from the sales of the central organization. It is to the State or local association that the grower goes for any information or to lodge any complaints that he may have.

An allotment of 2 per cent of total sales is made to defray the expense of these services. However, under ordinary circumstances a portion of this allotment is refunded to the grower.

TABLE 5.—*Operating expenses of State associations, 1920.*

Expenses.	Total barrels shipped, 284,019.		Massachusetts barrels shipped, 175,659.		New Jersey barrels shipped, 84,661.		Wisconsin barrels shipped, 23,699.	
	Amount.	Average per barrel.	Amount.	Average per barrel.	Amount.	Average per barrel.	Amount.	Average per barrel.
Salaries	$20,134.32	$0.0709	$13,500.72	$0.0769	$5,520.00	$0.0652	$1,113.60	$0.0470
Telegrams and telephones	1,730.32	.0061	1,028.67	.0059	701.65	.0083	(1)	.....
Labels	7,512.36	.0264	5,957.71	.0339	1,554.65	.0184	(1)	.....
Printing and office expenses	6,190.91	.0218	5,247.25	.0299	815.46	.0096	128.20	.0054
Travel	814.30	.0029	.....	.....	814.30	.0096	.....	.....
Rent	720.00	.0025	(2)	.....	600.00	.0071	120.00	.0051
Interest (actually paid)	4,595.75	.0162	3,547.22	.0202	1,029.39	.0122	19.14	.0008
Sundries	5,969.51	.0210	4,634.06	.0264	991.37	.0117	344.08	.0145
Total expenses	47,667.47	.1678	33,915.63	.1931	12,026.82	.1421	1,725.02	.0728
Income: 2 per cent of sales plus miscellaneous credits	61,703.67	.2172	36,590.35	.2083	18,889.21	.2231	[3] 6,424.11	.2711
Refund to growers [4]	11,726.01	.0413	2,674.72	.0152	6,862.39	.0811	2,188.90	.0924

[1] Included in sundries.
[2] This association owns its own building.
[3] $2,510.19 was placed in the surplus fund, which explains the difference between expenses plus refund to growers and the 2 per cent sales allotment.
[4] Two per cent of the sales is reserved for operating expenses. This item represents the portion of the reserve not used.

The operating expenses for 1920 were a little over 19 cents a barrel in Massachusetts, 14 cents in New Jersey, and 7 cents in Wisconsin. These differences are explained in a large measure by the differences in service performed. The Cape Cod district expends more money per barrel of fruit for inspection than either of the

other two districts. Furthermore, the expenses of the Massachusetts company included an experiment with a picking machine, made for the benefit of the growers, which alone exceeded the total operating expenses of the Wisconsin association. The Cape Cod growers are conducting experiments with a view to developing a power picking machine. In addition, this association operates company packing houses at cost for the benefit of small growers, which increases the overhead expense.

The average operating expense for all three local associations amounts to 16.8 cents a barrel.

THE CENTRAL ASSOCIATION.

The duties of the central selling organization begin where those of the local association cease. It becomes the selling agency for the local companies and renders all reports directly to the State companies and not to the growers individually. The central association takes complete charge of the berries after they are loaded into the car. It takes charge of all car diversions and keeps in close touch with the car until it reaches destination. It does all the selling and takes charge of all collections. Warehouses have been established in Chicago and other points where a large amount of cleaning and sorting is done on berries which have suffered deterioriation in transit. A traveling inspector is employed who travels over the country attending to serious claims which arise during the season. He attempts to locate the cause of the damage and fix the responsibility for it. The central association takes charge of all railroad claims that may arise. The advertising is entirely in its hands. It renders full accounts to the State companies of all sales and all charges which have accrued, such as storage, reconditioning or remilling, freight and cartage, and remits proceeds directly to them. For these services the central association is alloted 5 per cent of total sales. This allotment in 1920 amounted to 53½ cents a barrel. Actual operating expenses were only 46 cents a barrel, hence 7½ cents a barrel was returned to the grower.

Table 6—Operating expenses of central selling association, 1920.

[284,019 barrels handled.]

Disbursements.	Amount.	Average per barrel
1. Managers' and salesmen's salaries, brokerage fees and commissions to representatives in all markets	$85,845.76	$0.302
2. Printing, telegraphing, telephoning, rents, trade paper advertising, postage, credit agencies, legal advice and bonding	23,981.02	.084
3. Traveling expenses	6,238.62	.022
4. Salaries of office employees, New York and Chicago	12,822.51	.045
5. Bad accounts, charged off	1,574.44	.006
Total expenditures	130,462.35	.459
Reserve of 5 per cent of sales plus small miscellaneous income	151,995.10	.535
Refunded to State companies	21,532.75	.076

In addition to the above expense the central selling association spent $77,937.91 in advertising. This amount is equal to about 27½ cents for each barrel handled.

The usual brokerage rates on car-lot shipments are $20 a car which averages around 10 cents a barrel. In some of the Southern and Western States where the demand is lighter 15 cents a barrel is charged, while three Southern States reported a brokerage charge as high as 20 cents. By far the greater bulk is handled for 10 cents if in car-lot shipments. This fee is paid by the central association and is covered by the handling charge of 46 cents a barrel.

The total charge of both State and central cooperative association in 1920 was 62.7 cents a barrel.

ADVERTISING.

Expenditures for advertising amounted in 1920 to 27½ cents a barrel. An allotment of 35 cents a barrel was reserved, but because of the good demand for the product during the latter part of the selling season, it was not found necessary to expend the entire allotment.

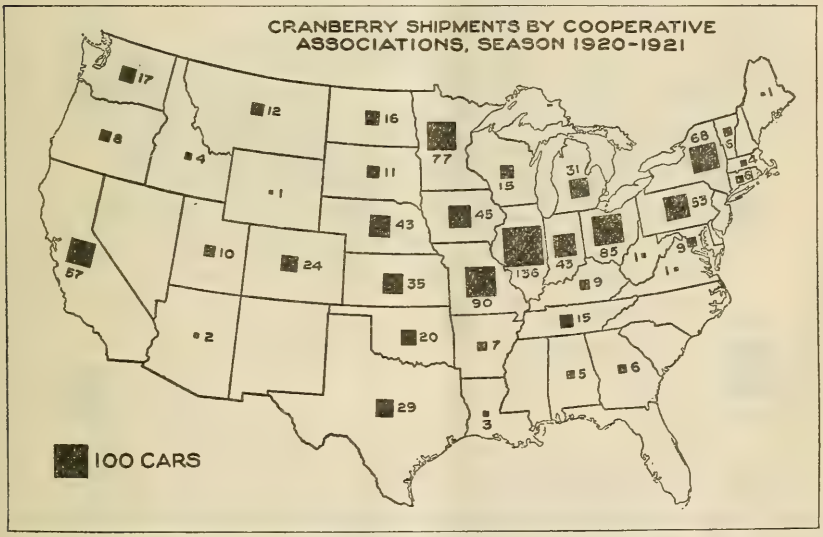

FIG. 7.—During the season 1920–21 the cranberry growers shipped cooperatively a total of 1,050 cars. These shipments went direct from producing districts to nearly every State in the Union. Forty-five cars not shown on the map were sent to Canada.

TRANSPORTATION.

Figure 7 is a graphic presentation of the car-lot shipments of the three cooperative associations through their central sales agency. This chart, together with the chart in Figure 5, shows that the Middle West furnishes the largest outlet for cranberries, and that the South consumes very small quantities in proportion to other sections of the country.

Figures 8, 9, and 10 show the car-lot shipments from Massachusetts, New Jersey and Wisconsin respectively. These charts show that there is no division of territory between the different associations. Even though such arrangement might be possible, and in a number of

cases might effect a saving in transportation costs, consumers' demands and trade practices make a division of territory highly impracticable, for, as has been stated, the different markets demand different kinds of cranberries.

"Cross freights" are often condemned for incurring what is termed an unjustifiable expense. However, in many cases the loss incurred by attempting to place goods regardless of consumers' demands and preferences would result in a far greater loss than that entailed by the "cross freights" incurred in catering to established trade wants.

The part which transportation plays in the cost of marketing cranberries has been estimated by taking the number of barrels shipped from each growing district to the various States and applying the

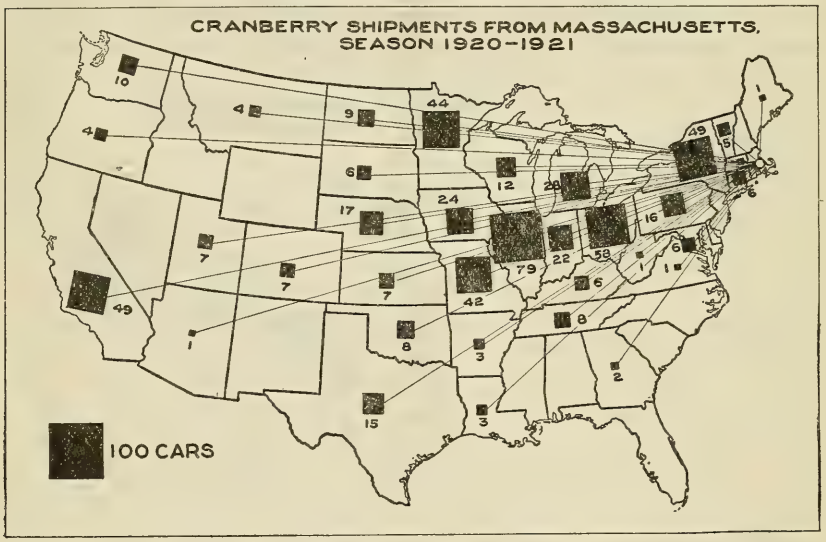

FIG. 8.—The Massachusetts association shipped 561 cars to 36 States and 40 cars to Canada.

freight rate from the principal shipping point in the growing State to the principal market in each consuming State. For instance, the cost of transportation on all berries shipped from Massachusetts to Iowa is based on the rate from the principal shipping point in Massachusetts to the principal city in Iowa. Estimated in this manner, the weighted average transportation cost for each district is as follows:

	Per barrel.
Massachusetts	$1.42
New Jersey	1.26
Wisconsin	1.10
All berries shipped through association	1.33

This estimate of $1.33 a barrel for the three districts does not cover the less-than-carlot shipments entailed in distributing cranberries to the retail trade from the jobbing centers. This expense is covered by the retailers' margin which is discussed later.

JOBBERS.

In answering a questionnaire 173 jobbers located in 26 States submitted handling margins on cranberries for 1920 which ranged from 4 per cent of selling price to more than 25 per cent. The range of jobbers' margins is shown below:

Margin:[1]	Number of jobbers
5 per cent or below	9
6 to 10 per cent	66
11 to 15 per cent	64
16 to 20 per cent	30
Above 20 per cent	4

The weighted average margin for all jobbers is 13.6 per cent of their selling price. The weighted average selling price of cranberries

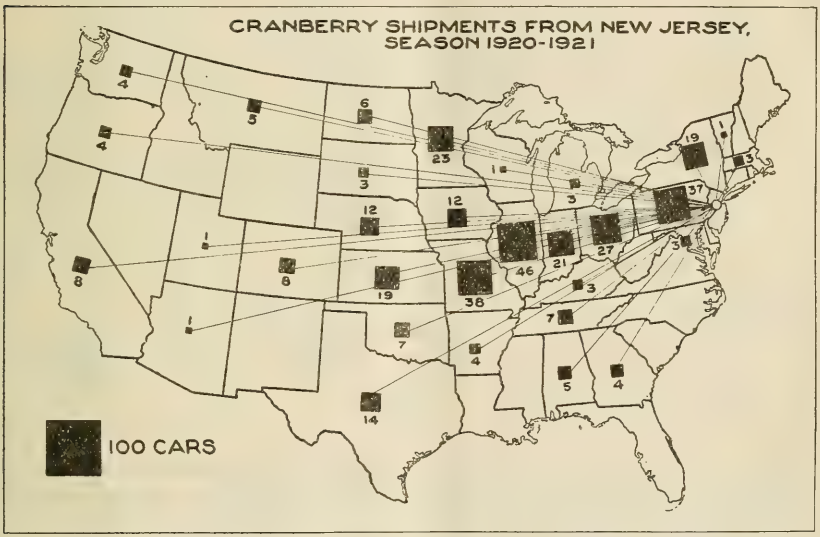

FIG. 9.—New Jersey car-lot shipments through the cooperative association amounted to 354 cars. Canadian shipments, not shown on the map, amounted to 5 cars.

by jobbers during October, November and December, the months of greatest sales, was $13.97 a barrel. Hence the jobbers' margin for the country as a whole was around $1.90 a barrel.

OTHER WHOLESALERS.

Although the jobber is the principal wholesaler of cranberries after they leave the hands of the exchange, some of the product is handled by more than one wholesaler in the same market. For instance, it is not unusual for a car-lot receiver to sell to a smaller wholesaler, or for a wholesaler to sell to a wagon peddler, who in turn supplies the retailer. This being the case, the jobber's margin does not cover the entire wholesale handling charge for all berries. It is difficult to as-

[1] Percentage of selling price.

certain the amount of the charges entailed by a second wholesaler, for it is not possible to learn the percentage of berries handled in this manner. However, it is believed that an allowance of 12½ cents a barrel on all cranberries marketed would cover the charges of "other wholesalers" for that portion of the product that is handled by a second or third wholesale agency.

RETAIL MARGINS AND PRICES.

Inquiry was made concerning the prices at which cranberries sold to the consumer during October, November, and December, 1920. Reports from 293 merchants in 26 States were collected showing that the retail price during these three months ranged from below 15 cents a pound in a few cases to above 30 cents a pound.

TABLE 7.—*Retail price of cranberries as reported in 26 States by retailers.*

Range of retail prices per pound.	Number and percentage of retailers selling at specified prices.					
	October.		November.		December.	
	Number of firms.	Number of firms reporting.	Number of firms.	Number of firms reporting.	Number of firms.	Number of firms reporting.
		Per cent.		*Per cent.*		*Per cent.*
Below 15 cents	25	9	15	5	8	3
15 cents to 19 cents	134	47	117	40	74	25
20 cents to 24 cents	89	32	121	42	125	43
25 cents to 30 cents	26	9	30	10	67	23
Above 30 cents	8	3	8	3	19	6
Total retailers	282	100	291	100	293	100
Weighted average price....(cents)	17.3		18.5		20.4	

It will be noticed that on the whole the weighted average retail price advanced 3.1 cents from October to December. The wholesale price advanced during the same period approximately 5½ cents a pound. This lag in the retail price is due largely to the fact that the retailer establishes his selling price on the basis of the wholesale price of cranberries at the beginning of the season but fails to advance the price as rapidly as the wholesale price advances. Furthermore, chain stores, cash-and-carry, and similar stores follow the practice of pushing cranberries as a leader on a very narrow margin during the Thanksgiving and Christmas holiday seasons. Such practices compel all stores to maintain low prices during this period in order to meet competition. Since chain and cash-and-carry stores are more numerous in the larger cities, this probably accounts for the fact that the retail price of cranberries was lowest in these places.

Of the total number of 282 retailers in 26 States, 8 reported handling margins below 10 per cent of the selling price, 6 reported margins of 10 to 14 per cent, 37 reported 15 to 19 per cent, 107 reported 20

to 24 per cent, 96 reported 25 to 29 per cent, 22 reported 30 to 34 per cent, and 6 reported 35 per cent and above. The weighted average margin for all stores reporting was 22.4 per cent of the retail selling price.

The average retail price of 18.7 cents a pound as reported by the 293 stores in cities of all sizes is not altogether representative in view of the fact that the greater amount of berries is sold in the larger cities at a slightly lower price. It is believed that 18 cents a pound is a representative estimate for the retail price of cranberries for the country as a whole during the three months under consideration.

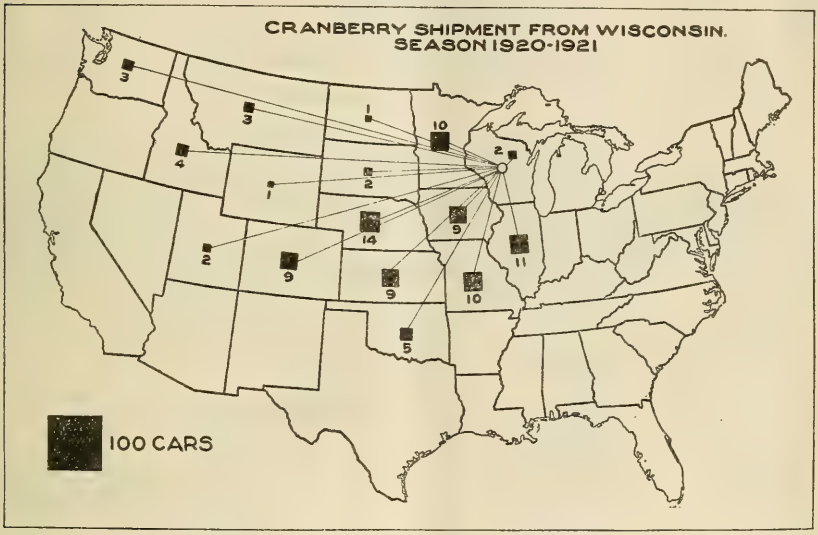

FIG. 10.—Wisconsin cooperative shipments cover a limited territory compared with the shipments of the other two districts. The 95 cars shipped in 1920–21 went almost entirely to the North Central and Western States.

The handling margins of retailers in 1920 ranged from around 10 per cent to above 35 per cent.

On the basis of a retail price of 18 cents a pound, or $18 a barrel, the retailer's margin for the period considered would amount to $4.03 a barrel. This means a margin of 4 cents a pound to cover retailer's handling expense. This retail handling expense is necessarily relatively heavy, for cranberries are sold to the ultimate consumer in small lots and all of the expense items of retail distribution enter in.

Table 7 gives the retail prices for cities of varying sizes. Retail prices from September 27 to December 4, 1920, at stores in 13 large markets are given in Table 8:[1] All of the stores visited reported a price below 17 cents a pound until after Thanksgiving Day.

[1] These data were gathered by representatives of the American Cranberry Exchange.

TABLE 8.—*Retail prices of cranberries at 13 large markets in 1920.*

[Total stores, 11,334.]

City.	Dates included, 1920.	Number of reports included.	Retail price per pound.
New York	Sept. 27 to Oct. 9	2,410	$0.16
Chicago	Oct. 11 to Oct. 23	2,907	.159
Milwaukee	Oct. 25 to Oct. 30	297	.156
Indianapolis	do	491	.157
Minneapolis and St. Paul	Oct. 25 to Nov. 6	626	.154
Detroit	do	596	.152
Cincinnati	Nov. 1 to Nov. 13	907	.151
Kansas City	Nov. 8 to Oct. 20	563	.162
Omaha	Nov. 1 to Nov. 13	513	.161
Toledo	Nov. 8 to Nov. 20	603	.158
Pittsburgh	Nov. 15 to Nov. 27	858	.23
Columbus	Nov. 22 to Dec. 4	563	.199

ALL MARKETING EXPENSES.

Table 9 gives a comparison of marketing expenses. It will be noticed by this table that the grower receives 54 per cent of the consumer's dollar for growing and packing the fruit. Although data are meager concerning the percentage of the retail price which the grower receives on other perishable fruits and vegetables, it is safe to say that on the whole this percentage is well below the 50-cent mark.

Transportation charges amounted to over twice the amount charged by the cooperative associations.

TABLE 9.—*Expense of marketing a barrel of cranberries, 1920–21.*[1]

Items.	Marketing expense.	Per cent of total expense.
Grower	$9.713	54.0
Cooperative marketing associations[2]	.627	3.5
Advertising	.275	1.5
Transportation	1.333	7.4
Jobber	1.899	10.5
Other wholesalers	.125	.7
Retailer	4.032	22.4
Realized on barrel at retail	18.004	100.0

[1] Based on a retail price of 18 cents a pound.
[2] Both local and central.

Jobbers and other wholesalers charged for their services an amount equal to the combined charges of the cooperative association and the transportation agencies, while the retailer's margin amounted to practically one-half the total marketing expense, yet it is doubtful if the retailer's margin was sufficient to cover more than his actual handling cost.

The conclusion drawn from this study is that the cranberry growers have built up an efficient marketing organization marked by two

outstanding facts: (1) During the year 1920 with a crop but slightly below normal (95 per cent of normal), in the face of rapidly falling prices on practically all other commodities, the cranberry market advanced throughout the selling season. (2) The grower received

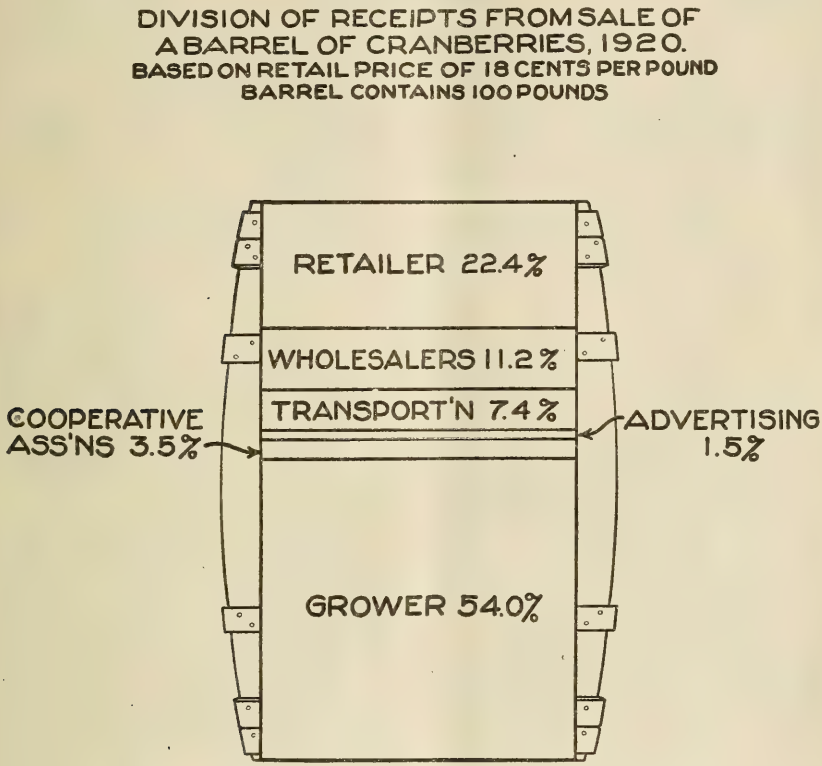

FIG. 11.—The 54 per cent of the retail price received by the grower for producing and packing cranberries is well above the amount received by producers of most other perishable fruit and vegetable products.

a greater percentage of the consumer's dollar than has been shown in studies of other perishable food commodities. In other words, the marketing expenses appear to be less than are ordinarily charged on similar products.

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UNITED STATES DEPARTMENT OF AGRICULTURE

BULLETIN No. 1110

Washington, D. C. PROFESSIONAL PAPER October, 1922

THE FARMER'S SHORT-BOX MEASURING FLUME.[1]

By Carl Rohwer, *Irrigation Engineer,*

Division of Agricultural Engineering, Bureau of Public Roads.

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Many devices have been developed for the measurement of the water delivered to farmers for irrigation, and of these the standard weirs have been most carefully calibrated. When weirs of this type have been correctly designed, installed, and maintained they give accurate results. In some localities, however, especially in the older irrigated sections, types of weirs have come into use that are not standard and that consequently can not give accurate results unless new calibrations are made. For one of the many weirs of this type the following tables and charts have been prepared in order that the structures already installed may be successfully used in the distribution of water.

The farmer's short-box measuring flume, as shown in Figure 1, is a weir with completely suppressed end contractions and a partially suppressed bottom contraction. No provision is made for the aeration and lateral expansion of the nappe, as required in the standard weir without end contractions. The floor of the weir box is level, and is placed at the grade of the ditch in which it is installed. The weir bulkhead is variable in height, depending on the conditions it has to fulfill, and it is usually made from the commercial sizes of 2-inch lumber. No attempt is made to keep a sharp edge at the crest. As shown in the figure, the bulkhead is not fixed, but may be removed, by sliding it out of the grooves in the walls of the weir

[1] The work upon which this bulletin is based was done with the assistance of M. L. Lightburn and A. B. Crosley under the direction of R. L. Parshall, senior irrigation engineer, in charge of the irrigation investigations in Colorado. The bulletin was prepared in cooperation with the Colorado Agricultural Experiment Station.

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box, for the purpose of cleaning the structure of sand and silt. This manipulation makes it difficult to restore the crest of the weir to its former elevation and has led to the practice of measuring the head, for free-flow weirs, on the crest instead of at the standard gauge point, or place for measuring the head. If, however, the weir becomes submerged, as frequently happens when large quantities are measured over low weirs, it is necessary to measure both the upstream and the downstream heads in order to find the discharge. In this case two gauge points, or places for measuring the head,

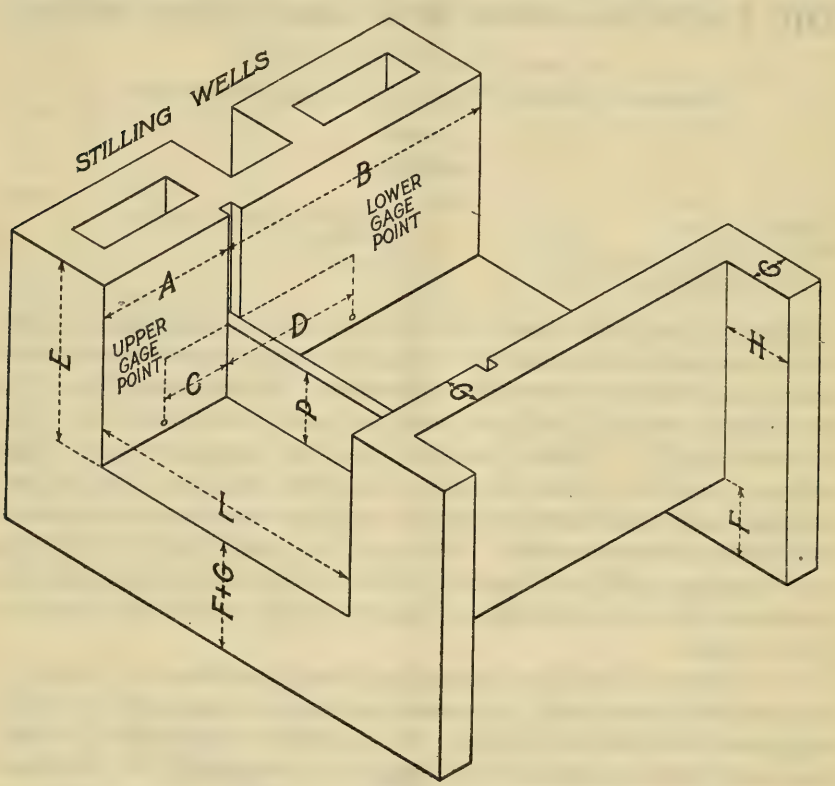

FIG. 1.—Standard plan of farmer's short-box measuring flume.

must be used, one above and one below the weir bulkhead. Both points should be at the same elevation. The floor of the weir box, which is level, may be used in an emergency, but under conditions in which submergence frequently occurs points located at the elevation of the weir crest are more convenient.

METHOD OF CALIBRATION.

For the purpose of simplicity in making the calibrations of the various sizes of flumes and heights of weirs, and in order to make the results comparable, it was necessary to adopt a standard design for

the weir box, a definite location for the gauges, and a uniform plan of conducting the tests.

Table 1 gives the standard weir-box dimensions and positions of the gauges. The letters used refer to Figure 1. It will be noted that the location of the gauges is the same for all the sizes of flumes. The discharge over this type of weir is very nearly proportional to the width of the flume, and therefore the condition of the flow is very nearly independent of the width; consequently, the position of the gauges need not be changed for the various sizes of flumes. The gauge point, 1 foot upstream from the weir bulkhead, was so located as to be outside the influence of the contraction lines of the water entering the flume, and not too near the crest. Because of the disturbed condition of the water below the crest the gauge point, 2 feet downstream from the weir bulkhead, was placed as far below the crest as the dimensions of the smallest flume would permit. The elevation of the zero of the gauges is not given. It depends on the height of the weir crest, and for convenience should be at the elevation of the crest.

TABLE 1.—*Standard dimensions for farmer's short-box measuring flumes.*

Size of weir.	Capacity of weir per second.	A Length of box above weir bulkhead.	B Length of box below weir bulkhead.	C Distance from weir bulkhead to upper gauge.	D Distance from weir bulkhead to lower gauge.	E Depth of flume.	F Depth of cut-off wall.	G Thickness of walls and floor.	H Length of wing walls.	L Length of weir crest.	P Height of crest.
Feet.	*Cubic feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Inches.*	*Feet.*	*Feet.*	*Feet.*
1	0.3 to 3.5	2	2.5	1	2	(1)	0.5	4	0.5	1	(2)
1.5	0.5 to 5	2	2.5	1	2	(1)	0.5	4	0.5	1.5	(2)
2	0.7 to 7	2	3	1	2	(1)	0.5	4	0.5	2	(2)
3	1 to 10	2	3.5	1	2	(1)	1	6	1	3	(2)
4	1.5 to 14	2	4	1	2	(1)	1	6	1	4	(2)

[1] The distance E depends on the height of P and the capacity required.
[2] The height of the crest P depends on the fall available in the lateral.

All the tests upon which the tables and charts are based were made at the hydraulic laboratory at Fort Collins, Colo.[2] The general arrangement of the apparatus used in the calibration is shown in Figure 2. The flume itself is similar to that shown in Figure 1, except that auxiliary walls, with a side slope of 1 to 1, have been attached to the upper end of the structure in order to approach more nearly the condition in a lateral. The points for taking the gauge readings are the same as in the standard measuring flume, but to increase the accuracy the gauge readings above and below the crest were taken by means of hook gauges located in the stilling wells

[2] For a complete description of the hydraulic laboratory, see Engineering News, vol. 70, No. 14, pp. 662-665, Oct. 2, 1913, V. M. Cone.

shown in the figure. At the same time the gauge readings on the crest were taken to the nearest one-sixteenth of an inch, with an ordinary carpenter's folding rule held vertically at the center of the flume and on the upstream edge of the crest. All the weir bulkheads were made of 2-inch material, having the upper edge or crest planed straight and at right angles to the side. Both corners of the crest were slightly rounded with sandpaper in order to approach field

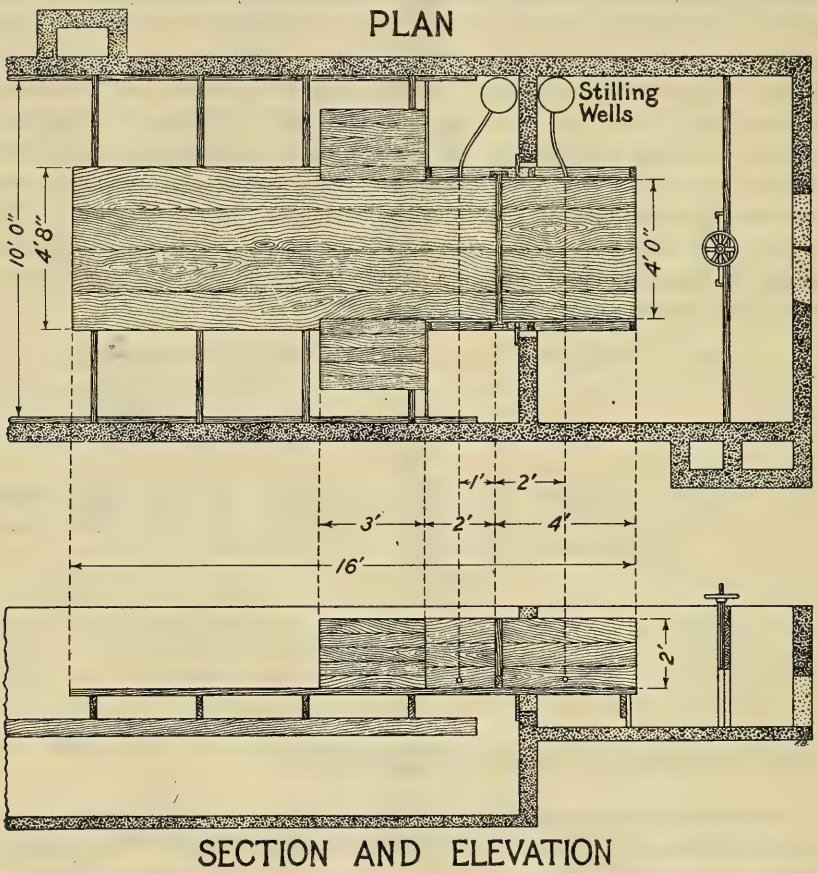

FIG. 2.—The farmer's short-box measuring flume, used at the Fort Collins laboratory.

conditions as nearly as possible. The discharge for each test was determined volumetrically in the calibration tanks at the laboratory.

In all, four sizes of flumes, each with four heights of crest, were calibrated. The flumes were 1, 2, 3, and 4 feet in width and the weirs were nominally 4, 8, 12, and 16 inches in height, but by measurement were found to be $3\frac{11}{16}$, $7\frac{1}{8}$, $10\frac{7}{8}$, and $14\frac{7}{16}$ inches, or 0.307, 0.594, 0.907, and 1.203 feet, respectively, in height. The thickness of the crest was in all cases $1\frac{9}{16}$ inches. For each width of flume and

height of crest a sufficient number of tests was made to locate definitely the position of the discharge curves for the free-flow and the submerged-flow conditions. This required a total of 271 tests, or about 17 tests each, for the 16 different settings. In addition, 8 special tests were made to determine the effect of various minor changes in the structure upon the discharge.

DERIVATION OF DISCHARGE FORMULAS.

The formulas for the free flow and for the submerged flow were deduced from these data. The discharge per unit width (1 foot) of flume was first determined for each head and height of weir. By comparing the discharges for unit widths of the different flumes for the same head and height of weir it was noted that there was no uniform difference in the discharges per unit width; therefore, in order to simplify the work, the average values were used. These values were plotted logarithmically, and from the lines drawn through the corresponding points the individual equations were determined. The free-flow and the submerged-flow equations were determined separately on account of the difficulty in determining a general equation for both conditions.

The equations for the two conditions are as follows:

Free flow:

$$Q=\frac{3.566}{(P-0.300)^{0.0164}}LH^{1.525} \qquad \text{(I)}$$

Where Q = discharge in cubic feet per second.
P = height of the weir in feet.
L = width of the flume in feet.
H = head in feet, measured at the upper gauge point.

Submerged flow:

$$Q=4.12\frac{H_d^{0.418\,(P-0.300)^{0.3605}}}{P^{0.170}}LH_a^{\frac{1.37H_d^{0.091}}{P^{0.128}}} \qquad \text{(II)}$$

Where Q = discharge in cubic feet per second.
P = height of the weir in feet.
L = width of the flume in feet.
H_a = head in feet measured at the upper gauge point.
H_d = difference of head in feet between the upper and the lower head.

Formulas I and II are empirical formulas based on the calibration of 1, 2, 3, and 4 foot flumes, with 4, 8, 12, and 16 inch weirs, for various heads and differences of head. They should not be used for larger or smaller flumes and weirs, nor for heads and differences of head beyond the limits of the experimental data. These limiting heads and differences of head are given in the tables and diagrams computed from the formulas.

The discharge values computed from Formula I agree very closely with the experimental data, except for heads of less than 0.2 foot. Formula II, however, which gives the submerged-flow discharges, does not give values that agree so closely with the experimental data. This is partly due to the variation in the observed discharges caused by the uncertainty of obtaining the true gauge heights. Formula II, like Formula I, does not give accurate results for heads of less than 0.2 foot. The agreement of the discharges computed from Formulas I and II for the free flow and submerged conditions, respectively, with the experimental discharges for the same conditions, is shown graphically in Figure 3. The percentages given in

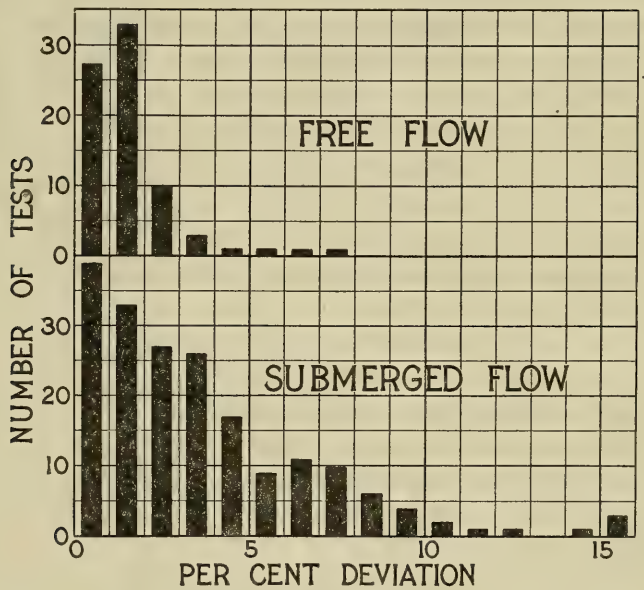

FIG. 3.—Deviation of the computed data from the experimental data for free flow and submerged conditions.

each case represent the deviation of the computed data from the experimental data. These diagrams indicate clearly that where accuracy is required the submerged condition must be avoided.

FREE-FLOW DISCHARGE TABLE.

Table 2 gives the free-flow discharges, in cubic feet per second, per foot in width of flume, for various heads and heights of weirs, computed from Formula I. The head at the upper gauge, which is used in the formula for computing the discharge, is given in both feet and inches at the left of the table. These values should be used to find the discharge in the table when the head is measured at the upper gauge point. If the head is measured on the crest, then the values in inches in the column to the left of the discharge column for the particular height of weir in question should be used. It will be noted

that the heads on the crest are not constant for the same upper-gauge head, but vary with the height of weir, and therefore care should be used to choose the proper column for the head. The discharge values given are for a 1-foot width of flume. To find the discharge for any width of flume it is only necessary to multiply the discharge given in the table by the width of the flume in feet. These tables, however, should not be used for flumes less than 1 foot or more than 4 feet in width.

TABLE 2.—*Free-flow discharges in cubic feet per second, per foot in width of farmer's short-box measuring flumes.*

[Computed from the formula $Q=\frac{3.566}{(P-0.300)^{0.0164}}LH^{1.525}$.]

Upper gauge head.		2 by 4 inch weir, 0.307 feet high.		2 by 6 inch weir, 0.450 feet high.		2 by 8 inch weir, 0.594 feet high.		2 by 12 inch weir, 0.907 feet high.		2 by 16 inch weir, 1.203 feet high.	
		Head on crest.	Discharge.	Head on crest.	Discharge.	Head on crest.	Discharge.	Head on crest.	Discharge.	Head on crest.	Discharge.
Feet.	*Inches.*	*Inches.*	*Sec.-ft.*	*Inches.*	*Sec.-ft.*	*Inches.*	*Sec.-ft.*	*Inches.*	*Sec.-ft.*	*Inches.*	*Sec.-ft.*
0.20	2 3/8	2 1/8	0.33	2 1/16	0.32	2 1/16	0.31	2 1/16	0.31	2 1/16	0.31
.21	2 1/2	2 1/4	.36	2 3/16	.34	2 3/16	.34	2 1/8	.33	2 1/8	.33
.22	2 5/8	2 5/16	.38	2 1/16	.37	2 1/4	.36	2 1/4	.36	2 1/4	.35
.23	2 3/4	2 7/16	.41	2 3/8	.39	2 3/8	.39	2 3/8	.38	2 3/8	.38
.24	2 7/8	2 9/16	.44	2 1/2	.42	2 1/2	.41	2 7/16	.41	2 7/16	.41
.25	3	2 11/16	.47	2 5/8	.44	2 5/8	.44	2 9/16	.43	2 9/16	.43
.26	3 1/8	2 3/4	.50	2 11/16	.47	2 11/16	.47	2 5/8	.46	2 5/8	.46
.27	3 1/4	2 7/8	.53	2 13/16	.50	2 13/16	.49	2 3/4	.49	2 3/4	.48
.28	3 3/8	3	.56	2 15/16	.53	2 15/16	.52	2 7/8	.52	2 7/8	.51
.29	3 1/2	3 1/8	.59	3 1/16	.56	3	.55	2 15/16	.54	2 15/16	.54
.30	3 5/8	3 3/16	.62	3 1/8	.59	3 1/8	.58	3 1/16	.57	3 1/16	.57
.31	3 3/4	3 5/16	.65	3 1/4	.62	3 3/16	.61	3 3/16	.60	3 1/8	.60
.32	3 13/16	3 7/16	.68	3 3/8	.65	3 5/16	.64	3 1/4	.63	3 1/4	.63
.33	3 15/16	3 1/2	.71	3 7/16	.68	3 7/16	.67	3 3/8	.66	3 3/8	.66
.34	4 1/16	3 5/8	.75	3 9/16	.71	3 1/2	.70	3 1/2	.69	3 7/16	.69
.35	4 3/16	3 3/4	.78	3 11/16	.74	3 5/8	.73	3 9/16	.73	3 9/16	.72
.36	4 5/16	3 13/16	.82	3 3/4	.78	3 3/4	.77	3 11/16	.76	3 5/8	.75
.37	4 7/16	3 15/16	.85	3 7/8	.81	3 13/16	.80	3 3/4	.79	3 3/4	.78
.38	4 9/16	4 1/16	.88	4	.84	3 15/16	.83	3 7/8	.82	3 7/8	.82
.39	4 11/16	4 3/16	.92	4 1/16	.88	4 1/16	.87	4	.86	3 15/16	.85
.40	4 13/16	4 5/16	.96	4 3/16	.91	4 1/8	.90	4 1/16	.89	4 1/16	.88
.41	4 15/16	4 3/8	.99	4 5/16	.94	4 1/4	.93	4 3/16	.92	4 1/8	.92
.42	5 1/16	4 1/2	1.03	4 3/8	.98	4 3/8	.97	4 5/16	.96	4 1/4	.95
.43	5 3/16	4 5/8	1.07	4 1/2	1.02	4 1/2	1.00	4 3/8	.99	4 3/8	.99
.44	5 1/4	4 13/16	1.11	4 5/8	1.05	4 9/16	1.04	4 1/2	1.03	4 7/16	1.02
.45	5 3/8	4 15/16	1.14	4 13/16	1.09	4 11/16	1.08	4 5/8	1.06	4 9/16	1.06
.46	5 1/2	4 15/16	1.18	4 15/16	1.12	4 3/4	1.11	4 11/16	1.10	4 11/16	1.09
.47	5 5/8	5	1.22	4 15/16	1.16	4 7/8	1.15	4 13/16	1.14	4 3/4	1.13
.48	5 3/4	5 1/8	1.26	5	1.20	4 15/16	1.19	4 7/8	1.17	4 7/8	1.17
.49	5 7/8	5 1/4	1.30	5 1/8	1.24	5 1/16	1.22	5	1.21	5	1.20
.50	6	5 3/8	1.34	5 1/4	1.28	5 3/16	1.26	5 1/16	1.25	5 1/16	1.24
.51	6 1/8	5 1/2	1.39	5 3/8	1.32	5 1/4	1.30	5 3/16	1.29	5 3/16	1.28
.52	6 1/4	5 9/16	1.43	5 7/16	1.36	5 3/8	1.34	5 5/16	1.33	5 1/4	1.32
.53	6 3/8	5 11/16	1.47	5 9/16	1.40	5 1/2	1.38	5 3/8	1.37	5 3/8	1.36
.54	6 1/2	5 13/16	1.51	5 11/16	1.44	5 9/16	1.42	5 1/2	1.40	5 1/2	1.40
.55	6 5/8	5 15/16	1.55	5 3/4	1.48	5 11/16	1.46	5 5/8	1.44	5 9/16	1.44
.56	6 3/4	6	1.60	5 7/8	1.52	5 13/16	1.50	5 11/16	1.48	5 11/16	1.48
.57	6 13/16	6 1/8	1.64	5 15/16	1.56	5 7/8	1.54	5 13/16	1.53	5 3/4	1.52
.58	6 15/16	6 1/4	1.69	6 1/16	1.60	6	1.59	5 15/16	1.57	5 7/8	1.56
.59	7 1/16	6 3/8	1.73	6 3/16	1.64	6 1/8	1.63	6	1.61	6	1.60
.60	7 3/16	6 7/16	1.78	6 5/16	1.69	6 3/16	1.67	6 1/8	1.65	6 1/16	1.64
.61	7 5/16	6 9/16	1.82	6 7/16	1.73	6 5/16	1.71	6 3/16	1.69	6 3/16	1.68
.62	7 7/16	6 11/16	1.87	6 1/2	1.77	6 7/16	1.75	6 5/16	1.73	6 1/4	1.72
.63	7 9/16	6 13/16	1.91	6 5/8	1.82	6 1/2	1.80	6 7/16	1.78	6 3/8	1.77
.64	7 11/16	6 7/8	1.96	6 11/16	1.86	6 5/8	1.84	6 1/2	1.82	6 1/2	1.81
.65	7 13/16	7	2.01	6 13/16	1.91	6 3/4	1.89	6 9/16	1.86	6 9/16	1.85
.66	7 15/16	7 1/8	2.05	6 15/16	1.95	6 13/16	1.93	6 11/16	1.91	6 11/16	1.90
.67	8 1/16	7 1/4	2.10	7 1/16	2.00	6 15/16	1.98	6 13/16	1.95	6 3/4	1.94
.68	8 3/16	7 3/8	2.15	7 1/8	2.04	7 1/16	2.02	6 7/8	2.00	6 7/8	1.98
.69	8 1/4	7 7/16	2.20	7 1/4	2.09	7 1/8	2.07	7	2.04	7	2.03

TABLE 2.—*Free-flow discharges in cubic feet per second, per foot in width of farmer's short-box measuring flumes*—Continued.

Upper gauge head.		2 by 4 inch weir, 0.307 feet high.		2 by 6 inch weir, 0.450 feet high.		2 by 8 inch weir, 0.594 feet high.		2 by 12 inch weir, 0.907 feet high.		2 by 16 inch weir, 1.203 feet high.	
		Head on crest.	Discharge.	Head on crest.	Discharge.	Head on crest.	Discharge.	Head on crest.	Discharge.	Head on crest.	Discharge.
Feet.	*Inches.*	*Inches.*	*Sec-ft.*	*Inches.*	*Sec.-ft.*	*Inches.*	*Sec.-ft.*	*Inches.*	*Sec.-ft.*	*Inches.*	*Sec.-ft.*
0.70	8 3/8	7 9/16	2.25	7 5/16	2.14	7 1/4	2.11	7 1/16	2.09	7 1/16	2.07
.71	8 1/2	7 11/16	2.29	7 1/16	2.18	7 5/16	2.16	7 3/16	2.13	7 3/16	2.12
.72	8 5/8	7 13/16	2.34	7 9/16	2.23	7 3/16	2.20	7 5/16	2.18	7 1/4	2.16
.73	8 3/4	7 7/8	2.39	7 11/16	2.28	7 9/16	2.25	7 3/8	2.22	7 3/8	2.21
.74	8 7/8	8	2.44	7 3/4	2.32	7 5/8	2.30	7 1/2	2.27	7 7/16	2.26
.75	9	8 1/8	2.49	7 7/8	2.37	7 3/4	2.35	7 9/16	2.32	7 9/16	2.30
.76	9 1/8	8 1/4	2.55	8	2.42	7 7/8	2.39	7 11/16	2.37	7 5/8	2.35
.77	9 1/4	8 3/8	2.60	8 1/8	2.47	7 15/16	2.44	7 13/16	2.41	7 3/4	2.40
.78	9 3/8	8 1/2	2.65	8 3/16	2.52	8 1/16	2.49	7 7/8	2.46	7 13/16	2.45
.79	9 1/2	8 9/16	2.70	8 5/16	2.57	8 3/16	2.54	8	2.51	7 15/16	2.49
.80	9 5/8	8 11/16	2.75	8 3/8	2.62	8 1/4	2.59	8 1/16	2.56	8	2.54
.81	9 3/4	8 13/16	2.81	8 1/2	2.67	8 3/8	2.64	8 3/16	2.61	8 1/8	2.59
.82	9 13/16	8 15/16	2.86	8 5/8	2.72	8 7/16	2.69	8 1/4	2.66	8 3/16	2.64
.83	9 15/16	9	2.91	8 3/4	2.77	8 9/16	2.74	8 3/8	2.71	8 5/16	2.69
.84	10 1/16	9 1/8	2.96	8 7/8	2.82	8 11/16	2.79	8 7/16	2.76	8 7/16	2.74
.85	10 3/16	9 1/4	3.02	8 15/16	2.87	8 3/4	2.84	8 9/16	2.81	8 1/2	2.79
.86	10 5/16	9 3/8	3.07	9 1/16	2.92	8 7/8	2.89	8 5/8	2.86	8 5/8	2.84
.87	10 7/16	9 1/2	3.13	9 3/16	2.97	8 15/16	2.94	8 3/4	2.91	8 11/16	2.89
.88	10 9/16	9 9/16	3.18	9 1/4	3.03	9 1/16	2.99	8 13/16	2.96	8 13/16	2.94
.89	10 11/16	9 11/16	3.24	9 3/8	3.08	9 3/16	3.05	8 15/16	3.01	8 7/8	2.99
.90	10 13/16	9 13/16	3.29	9 1/2	3.13	9 1/4	3.10	9 1/16	3.06	9	3.04
.91	10 15/16	9 15/16	3.35	9 9/16	3.19	9 3/8	3.15	9 1/8	3.11	9 1/16	3.09
.92	11 1/16	10	3.41	9 11/16	3.24	9 7/16	3.20	9 1/4	3.17	9 3/16	3.15
.93	11 3/16	10 1/8	3.46	9 13/16	3.29	9 9/16	3.26	9 5/16	3.22	9 1/4	3.20
.94	11 1/4	10 1/4	3.52	9 15/16	3.35	9 11/16	3.31	9 7/16	3.27	9 3/8	3.25
.95	11 3/8	10 3/8	3.58	10 1/16	3.40	9 3/4	3.36	9 1/2	3.32	9 1/2	3.30
.96	11 1/2	10 1/2	3.63	10 3/8	3.46	9 7/8	3.42	9 5/8	3.38	9 9/16	3.36
.97	11 5/8	10 9/16	3.69	10 1/2	3.51	9 15/16	3.47	9 11/16	3.43	9 11/16	3.41
.98	11 3/4	10 11/16	3.75	10 3/8	3.57	10 1/16	3.53	9 13/16	3.49	9 3/4	3.46
.99	11 7/8	10 13/16	3.81	10 7/16	3.62	10 3/16	3.58	9 15/16	3.54	9 7/8	3.52
1.00	12	10 15/16	3.87	10 9/16	3.68	10 1/4	3.64	10	3.60	9 15/16	3.57

In order to illustrate the use of the table in finding the discharge, assume a 1.5-foot flume with a 2 by 8 inch weir, and a head of 2⅜ inches measured on the crest. In the column headed "Head on crest" for the 2 by 8 inch weir, find the 2⅜-inch head, and on the same line, to the right in the column headed "Discharge," read 0.39 cubic feet per second. This is the discharge for a 1-foot flume. To find the discharge for a 1.5-foot flume, multiply 0.39 by 1.5 and get 0.58 cubic feet per second, the discharge for a 1.5-foot flume under conditions given above. Had the 2⅜-inch head been measured at the upper gauge, then it would have been necessary to find the head in the column headed "Head in inches" for the upper gauge and to read the discharge of 0.31 cubic feet per second on the same line in the discharge column for the 2 by 8 inch weir. The discharge for a 1.5-foot flume is then 1.5 times 0.31, or 0.46 cubic feet per second when the head is measured at the upper gauge. The difference in the two values obtained shows the necessity of using the proper column in finding the head.

TABLE 3.—*Decimals of a foot for each one-sixteenth of an inch.*

Inches.	0	1/16	1/8	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	11/16	3/4	13/16	7/8	15/16
0.....	0.000	0.005	0.010	0.016	0.021	0.026	0.031	0.037	0.042	0.047	0.052	0.057	0.063	0.068	0.073	0.078
1.....	.083	.089	.094	.099	.104	.109	.115	.120	.125	.130	.135	.141	.146	.151	.156	.162
2.....	.167	.172	.177	.182	.188	.193	.198	.203	.208	.214	.219	.224	.229	.234	.240	.245
3.....	.250	.255	.260	.266	.271	.276	.281	.287	.292	.297	.302	.307	.313	.318	.323	.328
4.....	.333	.339	.344	.349	.354	.359	.365	.370	.375	.380	.385	.391	.396	.401	.406	.412
5.....	.417	.422	.427	.432	.438	.443	.448	.453	.458	.464	.469	.474	.479	.484	.490	.495
6.....	.500	.505	.510	.516	.521	.526	.531	.537	.542	.547	.552	.557	.563	.568	.573	.578
7.....	.583	.589	.594	.599	.604	.609	.615	.620	.625	.630	.635	.641	.646	.651	.656	.662
8.....	.667	.672	.677	.682	.688	.693	.698	.703	.708	.714	.719	.724	.729	.734	.740	.745
9.....	.750	.755	.760	.766	.771	776	.781	.787	.792	.797	.802	.807	.813	.818	.823	.828
10.....	.833	.839	.844	.849	.854	.859	.865	.870	.875	.880	.885	.891	.896	.901	.906	.912
11.....	.917	.922	.927	.932	.938	.943	.948	.953	.958	.964	.969	.974	.979	.984	.990	.995

SUBMERGED-FLOW DISCHARGE DIAGRAMS.

The discharge diagrams, Figures 4, 5, 6, 7, and 8, for submerged flow, are based on values computed from Formula II. These diagrams were used instead of tables on account of the difficulty of pre-

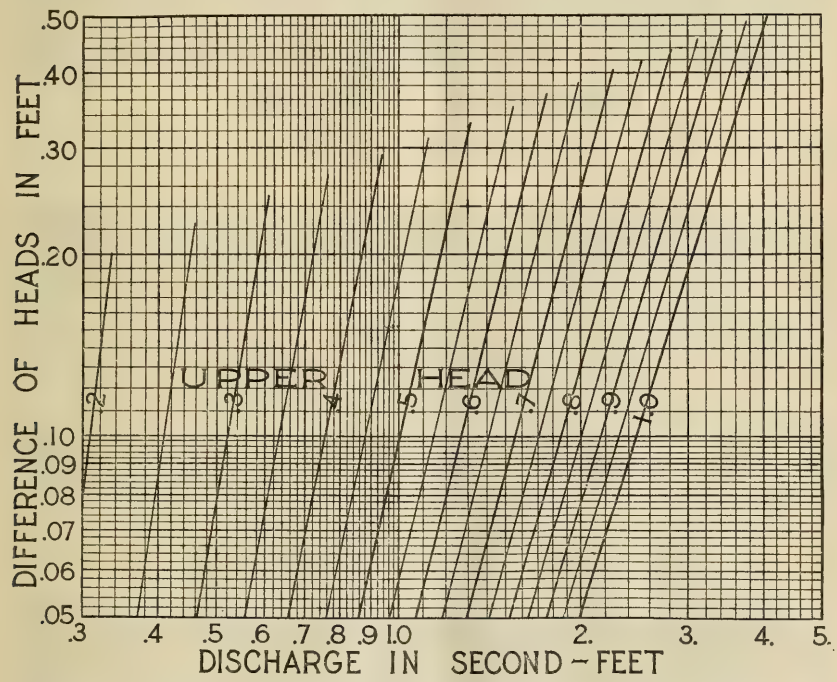

FIG. 4.—Discharge diagram for a 1-foot farmer's short-box measuring flume with a 4-inch weir, plotted from results computed from Formula II.

senting the data in tabular form. The logarithmic scale, which is used for all the diagrams, simplifies the plotting and increases the legibility for small differences in head. To illustrate the use of the diagrams in finding the discharge, assume a 3-foot flume with a 2 by

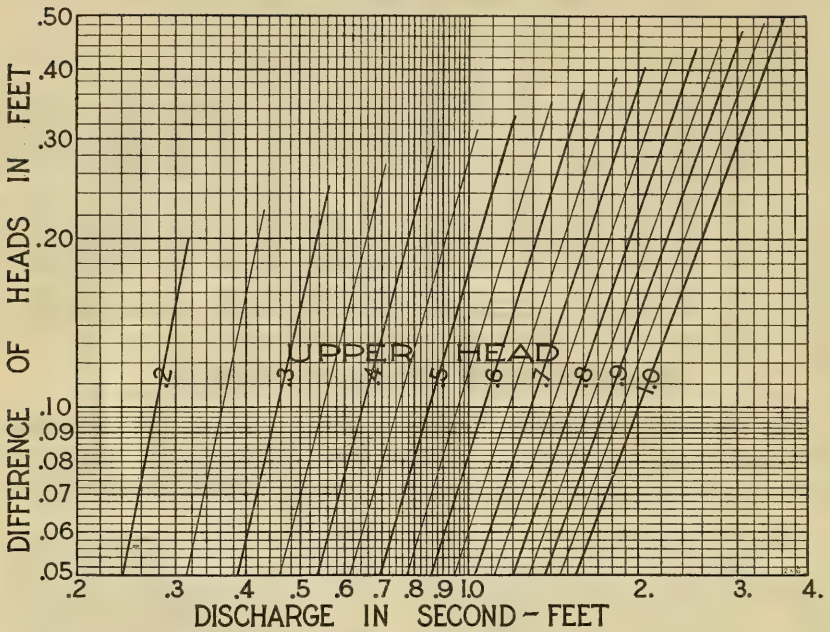

FIG. 5.—Discharge diagram for a 1-foot farmer's short-box measuring flume with a 6-inch weir, plotted from results computed from Formula II.

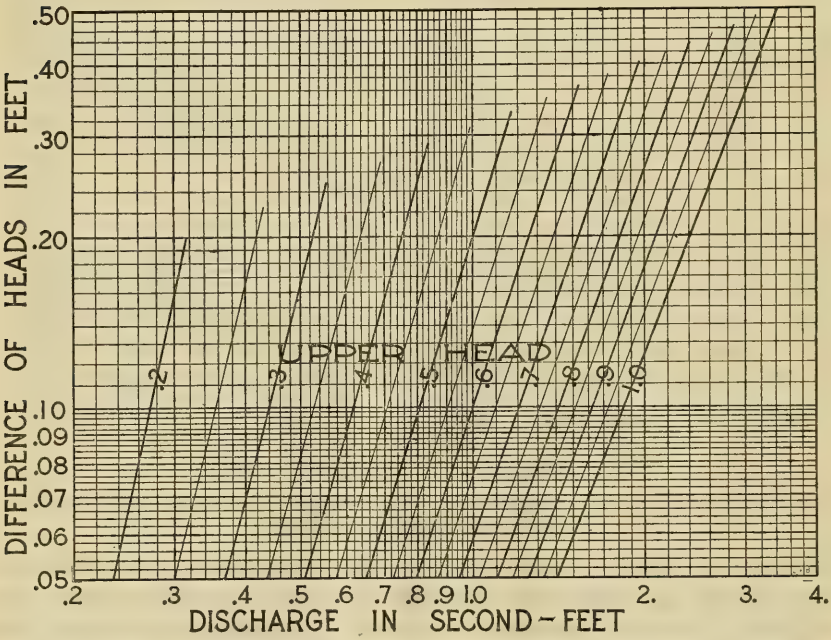

FIG. 6.—Discharge diagram for a 1-foot farmer's short-box measuring flume with an 8-inch weir, plotted from results computed from Formula II.

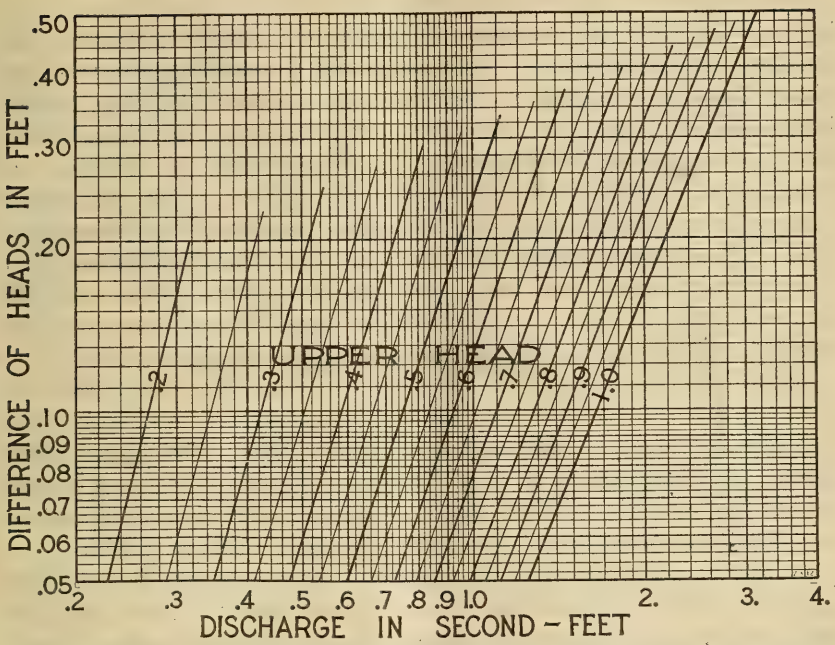

FIG. 7.—Discharge diagram for a 1-foot farmer's short-box measuring flume with a 12-inch weir, plotted from results computed from Formula II.

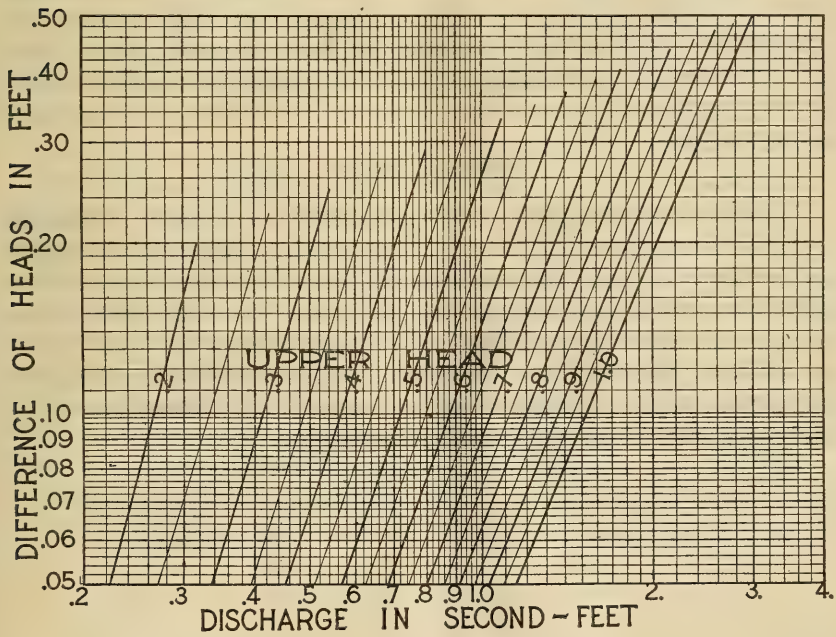

FIG. 8.—Discharge diagram for a 1-foot farmer's short-box measuring flume, with a 16-inch weir, plotted from results computed from Formula II.

16 inch weir, an upper head of 6½ inches and a lower head of 4¼ inches. To find the discharge, it is first necessary to convert the heads in inches into feet. This conversion is readily made with the aid of Table 3, which shows that 6½ inches equals 0.542 foot and 4¼ inches equals 0.354 foot. Of course, if both heads are measured in feet, no conversion is necessary. In order to find the difference of head, subtract 0.354 from 0.542 and get 0.188 foot, or approximately 0.54 and 0.19, respectively, for the upper head and the difference of head. Next turn to Figure 8, which is the discharge diagram for a 2 by 16 inch weir 1 foot long. On the left of the diagram find the horizontal line for the 0.19 difference of head, follow it to the right until the 0.5-upper-head line is reached, estimate the position of the 0.54-line, and then find where the 0.19 difference-of-head line cuts the 0.54-upper-head line, and directly beneath this point read 0.98 cubic feet per second as the discharge for a 1-foot flume. Then for a 3-foot flume, the discharge is 3 times 0.98 or 2.94 cubic feet per second under the conditions given above. These diagrams should not be used for flumes less than 1 foot nor more than 4 feet in width.

It will be observed that the diagrams do not cover the complete range of differences possible for each upper head; in fact, only the small differences are shown except for the small upper heads. This is due to the difficulty in obtaining these heads in practice. Where large flows with large differences in head are measured, the velocity of the water is so great below the crest that there is very little tendency to submerge the weir until the retardation below is quite great. It is doubtful even, if these large differences of head are possible except for very high weirs which tend to reduce the velocity of the water below the crest.

SPECIAL TESTS.

The results of the special tests to determine the effect of changes in the flume are given in Table 4. The results of these tests show that neither the changes in the crest nor the changes in the approach condition cause errors greater than 3.3 per cent. For submerged conditions, the errors would probably be less on account of the lower velocities of flow. This indicates that the changes which ordinarily occur in the field would not cause serious errors in the measurements of discharges from this type of measuring device.

TABLE 4.—*Showing the per cent of error in free flow and discharges due to various changes in the flume.*

Upper gauge head.	Size of flume.	Size of weir bulkhead.	Condition.	Discharge.	Standard experimental discharge.	Difference.	Error
Feet.	*Feet.*	*Inches.*		*Sec.-ft.*	*Sec.-ft.*		*Per cent.*
0.400	1	2 by 12	Both edges of crest rounded to curve of ¼ inch radius	0.926	0.896	0.030	3.3
.800	1	2 by 12		2.698	2.686	.012	0 4
.400	1	2 by 12	Rounded crest replaced by sharp metal crest	.882	.896	−.014	−1.6
.800	1	2 by 12		2.604	2.686	−.082	−3.1
.200	1	2 by 4	Standard crest. Auxiliary walls set vertical at a distance of 3 inches back from the sides of the flume	.333	.336	−.003	−0.9
.800	1	2 by 4		2.786	2.741	.045	1.6
.200	1	2 by 12		.323	[1] .313	.010	3.2
.800	1	2 by 12		2.713	2.686	.027	1.0

[1] Curve value, experimental discharge not determined for this head.

SUMMARY.

The farmer's short-box measuring flume was calibrated in order to make possible the successful use in the distribution of water of the structures of this type already installed.

The accuracy of the device is sufficient for ordinary requirements, but it is not to be recommended in preference to the standard types of weirs.

A comparison of the experimental discharges with the computed discharges for the free flow and for the submerged conditions shows that 77 per cent of all the free-flow computed discharges are in error by less than 2 per cent, and that 74 per cent of all the submerged-flow computed discharges are in error by less than 5 per cent.

The results show that the submerged condition should be avoided if possible.

For free-flow conditions, the gauge height may be measured either on the crest of the weir or 1 foot upstream from it. Care should be taken not to confuse the readings taken at the different points, when using the discharge tables.

For submerged conditions, both the upstream and the downstream heads must be measured. On account of the disturbed condition of the water, it is recommended that, in order to increase the accuracy, the heads be measured in stilling wells placed outside of the flume.

The discharge formulas are not applicable for heads greater or less than those given in the tables and diagrams, nor for flumes greater than 4 feet or less than 1 foot in width.

Changes, such as might occur in the flumes in the field, do not affect the discharge sufficiently to impair the usefulness of the device.

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ONE-VARIETY COTTON COMMUNITIES.[1]

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PURE COTTON SEED A FUNDAMENTAL REQUIREMENT.

To avoid mixture and degeneration of seed, only one variety of cotton should be grown in each community or district. Many other improvements may be urged, but having pure seed to plant is a basic need. Where different varieties of cotton are planted in neighboring fields and taken to the same gins, it is out of the question to keep the seed pure. The gins mix the different kinds of seed, crossing takes place in the fields, the varieties are mongrelized and cease to be uniform, the fiber deteriorates in quality, and the seed becomes unfit for planting.

[1]At the end of this bulletin references are given to previous publications in which the community features of cotton improvement have been recognized. Several paragraphs in this bulletin have been adapted from statements of the same matters in earlier papers which are no longer available for distribution.

Lack of pure seed is responsible for a general failure to utilize superior varieties of cotton and for enormous industrial and economic wastes through the production of inferior fiber and the manufacture of weak, perishable fabrics. The cotton industry absorbs the activities of millions of people, which could be applied to better advantage in raising better crops of cotton and making better goods. The producing and manufacturing operations are on a low plane of efficiency, working with raw material of needlessly inferior quality because the seed is poor. It is self-evident that the breeding of superior varieties does not result in the improvement of the cotton industry unless good seed becomes available and is used generally as the basis of production. Seed is necessary to raise cotton, and good seed must be planted if good fiber is to be obtained. The pure-seed problems must be solved, as well as the breeding problems, before superior varieties can be utilized.

Through the simple expedient of adhering to one variety in each community, the present degenerate mixed stocks could be replaced with pure seed of superior varieties. Cooperation, to the extent of agreeing to plant the same variety of cotton, is necessary if farmers are to have regular supplies of pure seed for their own use or to sell. The individual farmer, struggling alone with the idea that he can improve his crop and get a higher price in growing better fiber, is much more likely to fail than to succeed, but the prospect is altered completely when a whole community of farmers adopts and maintains an improved variety. Through community action it is possible to observe the necessary precautions, so that superior varieties can be preserved, increased, and utilized. This has been demonstrated in the striking progress made in recent years in the Salt River Valley of Arizona, where the growers have specialized on a single variety.

Considered as a means of utilizing superior varieties, community organization is as practical a need and as definitely related to the improvement of production as the invention of a new implement to cultivate the crop, a new fertilizer to stimulate the growth of the plants, or a new spray to keep off pests or diseases. Farmers and agricultural promoters would understand readily if superior varieties of cotton had to be grown on particular soils or special cultural treatment had to be given, but one-variety community organization is also to be reckoned as a condition or requirement for the production of good fiber. Though not so generally or so easily recognized by those who have been accustomed to think only of the farm operations, the community conditions may reduce or increase the profits of production as definitely as the other conditions of soil, rainfall, weevil infestation, or labor supply.

DISADVANTAGES OF MIXED-VARIETY PRODUCTION.

That so simple an expedient as the one-variety organization of cotton communities should have been overlooked so long may seem remarkable, but it should not keep us from recognizing the facts. Now that the serious defects of the present unorganized condition are recognized, more attention may be given to securing a substantial basis of progress in the cotton industry through improved and standardized production in one-variety communities. The problems of community cooperation are a field of research that needs to be cultivated at the present time for the general welfare of the cotton industry, to place production on a basis of superior varieties.

That the individual farmers of the same neighborhood should raise different kinds of cotton is as unreasonable, impracticable, and uneconomic as that each operative in a textile mill should spin a different kind of thread or weave a different kind of cloth. From the standpoint of progress in other branches of the cotton industry the lack of organization in the field of production appears as a very backward condition. The technical problems—the breeding of superior varieties, growing the crop, spinning thread, and weaving cloth by machinery—are much farther advanced than the general commercial problems of getting good cotton produced and supplied to the textile industry.

If the present system of mixed-variety production had been planned or chosen for some practical end that would need to be sacrificed in establishing one-variety communities, the case would be less clear, and an adequate discussion would require a careful balancing of the advantages to be gained against those that would be lost by communities restricting themselves to a single variety. But no argument has been developed or advantage claimed for the present condition of miscellaneous, unorganized production. The system of public gins, that destroys varieties by mixing the seed of different sorts together, has had a very gradual and unconscious development in the half century since the Civil War period.

Keeping good stocks of seed was much more feasible on the old plantations. Many of the large estates were well isolated, grew only a single variety, and had their own separate gins, so that a form of community production existed, a condition that gave place to separately operated small farms and tenant holdings and to the establishment of public gins, with the incidental result of the general mixing of seed. The changes of the farming system in the recent decades have resulted from other causes, with no relation to the need of uniform varieties or of pure-seed supplies. The pure-seed problems have had consideration only in recent years, after superior varieties had been bred and the utilization of those varieties became a practical question. It naturally was supposed that good

varieties needed only to be bred and distributed to the farmers, but experience showed that further attention must be given if varieties are to be preserved and utilized. Certainly no adequate utilization is to be expected under a system of production that mixes the varieties together, so that the work of selection is immediately undone as soon as commercial production begins.

The damage to the industry that might be charged every year to the lack of good seed and the resulting failure to utilize fully the resources of production that are applied to cotton would amount to hundreds of millions of dollars. Replacement of the present inferior mixed stocks by superior uniform varieties would give a direct gain of at least 10 per cent in quality and as much more in yield. Another 10 per cent increment might be expected from cultural improvements that are more feasible in one-variety communities, while advantages from community handling and marketing of a standardized product would not be less important than the other items, and the sale of pure seed is a further resource of one-variety communities. In returns or profits for the farmer, our present unorganized production of cotton may have only a 50 per cent efficiency as compared with what might be found possible if improved varieties and methods were regularly used in organized one-variety communities. The general waste of labor and resources of production in the eastern cotton belt contrasts painfully with the one-variety communities of the Salt River Valley of Arizona, where the Pima variety of Egyptian cotton is grown exclusively and the advantages of community organizations are beginning to be realized.

Nobody who considers the possibility of community organization of the cotton industry will doubt that the same land and labor can be made to produce more and better cotton under community conditions. From the standpoint of utilization of improved varieties and methods it becomes apparent that a faulty organization of the industry, or lack of organization, now interferes with the general application of practical results of scientific investigation. Since there is no question that production should be based on superior varieties, an expedient that would make this possible is worthy of the consideration of those who are interested in or responsible for the progress of the cotton industry. The one-variety plan seems fundamental because it is the only way that has been suggested for maintaining supplies of good seed, that are an absolute requirement for any general or well-established improvement of production. That it is difficult for communities to agree, and possible for a persistently careless or obstinate farmer to interfere with the progress of his neighbors and contaminate their seed stocks by refusing to plant a superior variety, is the most serious objection advanced thus far, but the existence of such obstacles only shows the need of more in-

formation and interest in securing community agreement if supplies of good seed are to be maintained.

If farmers had to pay a tax or license of a cent a pound in order to plant cotton of a different variety from their neighbors it is not likely that many would pay the money to indulge in their individual opinions, but they might become acutely interested in having the best variety grown so that the whole community might agree to plant this one kind and avoid paying the tax for miscellaneous planting. Unconsciously, however, cotton farmers generally are paying more than $5 a bale for operating under the present system of unorganized production, with different varieties grown on neighboring farms, if not actually on the same farm, taken to the same gin and sold indiscriminately to the same buyers.

A cent a pound, or $5 a bale, would be a very low estimate of the advantage that might be gained by community effort through the simplest precautions of planting even a medium quality of seed of one recognized variety and marketing its cotton together in even-running commercial lots, without considering the further improvement of fiber quality or the larger yields that can be had by adopting and maintaining superior varieties in place of the mixed stocks that furnish so large a proportion of the present cotton crop. The full advantage that could be expected in most places by using good varieties and other improvements that are possible under the community plan would be estimated between 5 and 10 cents a pound, with more in special cases as experience already has shown. This means that the farmers' profits may often be doubled by applying the improvements that are now definitely in sight under the community plan.

With gradual improvement of machinery, spinning of finer threads from short cotton has been accomplished, so that inferior fiber can be used for most of the textile articles that in the early days of cotton manufacture would have required much better raw material. Relatively small quantities of long, strong fiber have continued to be used for special purposes, such as sewing thread, automobile tires, and high-pressure fire hose. The special uses have increased notably in recent years with the development of the automobile industry, and the supplies would be far below the normal requirement if extensive substitution of short fiber were not practiced, even in articles that require strength and durability and should be made of good material.

On account of the present scarcity and acute demand for better cotton the manufacturing and commercial interests are recognizing the need of research for the improvement of the product, but without understanding that improved systems of production and of buying

and handling the crop are as necessary as improved varieties. The special biological problems of breeding and maintaining varieties have been solved, but not the general agronomic and economic problems of providing for the utilization of varieties. Not only the facts regarding varieties and textile qualities of different kinds of fiber need to be investigated by the manufacturers, but also the production and handling of the crop, the whole field of activity that lies between the breeding of varieties and the uses of cotton goods by the consuming public. For lack of such knowledge the manufacturers are unable to take a really practical and constructive interest in the development of the cotton industry as a whole and are unable to protect themselves against the adverse tendencies of the commercial system. Thus there is great need of closer study by manufacturers of the underlying commercial and agricultural factors that determine the production of good or poor fiber.[2]

SUPERIOR VARIETIES NOT UTILIZED.

No other plant product figures in our industrial civilization more largely than cotton, and the need of uniformity is greater with cotton than with any other crop. Fiber that is not uniform does not spin well nor make strong, durable fabrics. More labor is required to use inferior fiber, because the threads break more frequently in spinning and weaving. If the fiber is of good quality all the work of producing and manufacturing cotton is done to better advantage and the public is served with better goods. It seems not improbable that the value for textile purposes of most of the cotton grown in the United States could be at least doubled by using superior varieties, but such utilization of varieties is not possible without adequate supplies of pure seed, which are not maintained under the present system of production.

The need of improving the cotton crop is being recognized in all the principal regions of production. Experiment stations in different parts of the world are engaged in the breeding or testing of varieties of cotton and devising improved cultural methods. Each of the cotton-growing regions has its own series of diverse forms and variations to study, in addition to efforts in many countries to introduce foreign kinds and adapt them to the local conditions. Nevertheless, only a very limited application of the results of breeding investigations is to be expected, either in the United States or in other cotton-growing regions, unless the organization of the industry can be improved so that superior varieties can be utilized.

Rich possibilities of improvement have been shown in the species and varieties of cotton that have been studied intensively. Many

[2] Cook, O. F. Commercial parasitism in the cotton industry. *In* Nature, v. 105, no. 2644, p. 548–549.

superior strains have been developed, and the methods of breeding have been improved until they are far in advance of methods of utilization of varieties. But in spite of the value of good varieties being recognized, the need of special precautions for large-scale production of superior fiber has received very little consideration. Instead of select, uniform stocks being isolated and preserved by continued selection, new varieties usually are mongrelized and begin to "run out" as soon as they are planted on a commercial scale. While this mongrelizing system is followed it is impossible to keep varieties uniform or to develop large stocks of pure seed. The system of mixed-variety production has been tested on an enormous scale and for a long period of years and leaves no doubt of its adverse effects. No general or complete utilization of superior varieties seems possible under the present system of miscellaneous planting of different sorts.

Though it seemed reasonable to suppose that commercial seed firms would maintain the selection of superior stocks and meet the public demand for pure seed, dealers have the same difficulties as the farmers themselves in maintaining the production of pure seed. Most of the commercial seed is raised by farmers without special isolation of the fields and without precautions of separate ginning. Dealers have no way to get large quantities of pure seed unless they deal with one-variety communities or go into cotton farming on a large scale, in addition to conducting their business as seed merchants. To be effective for keeping seed pure the scale of farming must be large enough to provide isolation and separate ginning, or, in other words, to form a separate cotton community for producing the seed supplies of each variety handled, which for most seedsmen is out of the question.

Efforts that some of the more enterprising seed firms have made to supply themselves with high-quality seed have been abandoned, because no way was found to develop and maintain uniform stocks, even when very desirable novelties had been originated. Without doubt, reliable dealers will buy their stocks of seed from one-variety communities as soon as there is a sufficient volume of production of pure seed to meet the commercial demand. In the early stages of development of a new variety or select strain, general distribution, by sale or otherwise, is undesirable, because most of the seed that is sent out in small quantities is lost by becoming mixed with other varieties. Production of the pure seed on a practical scale is essential, whether handled later through commercial seed firms or from one community to another.

DISTRIBUTION OF NEW VARIETIES INEFFECTIVE.

When systematic cotton breeding was first undertaken by the United States Department of Agriculture, it was supposed that

superior varieties would be adopted readily, so that only small quantities of select seed would need to be distributed, which farmers or seedsmen would promptly increase for large-scale production. Several new kinds of special selections of different varieties were furnished in each distribution for several years, but the results did not justify the expectation that superior varieties would be readily and promptly utilized. It was not understood by the farmers or the seedsmen that the supplies of seed were limited to the stocks that were distributed, and no effective precautions were taken to develop or maintain large supplies of seed of the new varieties or the select strains.

Instead of serving a useful purpose, the plan of making single distributions of new kinds of seed seemed only to be adding to the general mixture of sorts. Further experience showed that even repeated distributions of seed in small quantities, of even the most desirable new kinds, did not result in the varieties becoming established in cultivation. Many farmers sent very favorable reports on the behavior of the new varieties, but only a few saved the seed separately, and very few cases were found, either among farmers or professional seedsmen, who on their own account maintained the isolation of the fields and separate ginning of seed long enough to reach the stage of commercial production.

Thus, the method of distribution that was first projected did not result in establishing commercial supplies of pure seed. Several of the varieties that were developed and distributed in the early years of the cotton-breeding work were lost completely before the system of distribution was changed. The difficulty and uncertainty of securing these fundamental precautions, even among farmers who had active interest and were in voluntary cooperation with the Department of Agriculture, led finally to a clear recognition of the need of establishing one-variety communities. No other way has been suggested for maintaining and increasing stocks of pure seed on a scale that would provide for the general utilization of superior varieties. Further study and experience with one-variety communities have only confirmed and added to the reasons that were given in the first statement of the plan, published in 1911.

To avoid some of the defects of the plan that had been followed for several years, a change in the method of conducting the distribution of cotton seed was recommended and adopted in 1913. Smaller packages of seed, a quart instead of a peck, were used for the general distribution, but supplemented in the following year by a special distribution of half-bushel lots to a select number of farmers located in the most favorable districts for the particular varieties, as shown by reports furnished, supported by actual samples of bolls showing

when definite advantages have been shown and seed supplies are available, so that all neighboring farmers may change together to the new variety.

RENAMING VARIETIES OF COTTON.

The practice of renaming varieties is one of the obstacles in the way of a more general understanding and application of the one-variety plan, as tending to conceal or obscure the fact that the same variety of cotton can be maintained and utilized in the same community for many years with no deterioration or "running out" if isolation and selection are maintained.

No doubt the renaming of varieties is, at least in part, a concession to the popular idea that new kinds are needed every few years. Knowing that this idea is prevalent, the dealers suppose that more seed can be sold under new names than by continuing to offer old and well-known varieties. With the public better informed regarding the value of good varieties and the need of maintaining supplies of pure seed, the policy of renaming varieties may be altered. Farmers who are sufficiently intelligent to buy good seed in practical quantities prefer to know what they are buying, whether it is a variety already known or a new and different sort. They do not wish to buy even good seed under a new or unnecessary name.

Special quality of seed is properly to be claimed if careful selection of the basic stocks is continued and the seed-increase fields are inspected to see that the plants are uniform and to remove the off-type individuals that continue to appear even in the best stocks. But the use of precautions to keep a variety pure is not a reason for changing the name. Discarding the original name tends rather to confuse the public and to restrict the use of the variety instead of securing a wider appreciation of its value. In view of the general scarcity and active demand for good seed of such varieties as Columbia and Lone Star, it is difficult to believe that anything was gained by advertising some of the seed stocks under new names, like "Webber" or "Bennett." The Foster variety, also originated and distributed by the United States Department of Agriculture, was exploited for several years in Mississippi and in the Imperial Valley of California as "Unknown." At Yuma, Ariz., in 1919, a stock of Durango seed was sold as "Rowden" to settlers from Texas who were anxious to grow the true Rowden cotton, a big-boll sort that is very popular in some of the sandy land districts of Texas. But the so-called "Rowden" of the Yuma Valley attracted further attention by yielding a premium staple, and now a "California Improved Rowden" is being advertised in Texas as a new and valuable long-staple Upland variety.

Possibly it might be argued in such cases that varieties bred and distributed by the United States Department of Agriculture are considered as public property and that the new names are required for proprietary advertising purposes, so that higher prices can be charged in accordance with the general custom of seedsmen to regale their customers with high-priced novelties every year. But if prices were not so high the volume of business might be larger if really good seed of tested and recognized varieties was known to be available. The present policy leaves out of account the fact that any variety, no matter how it was originated, needs to become widely and favorably known before there can be any very large or regular demand for the seed. The legitimate advertising value of the fact that a variety was originated and distributed by the United States Department of Agriculture after being tested carefully in many localities is now recognized by some of the seedsmen. However, the practice of renaming varieties is by no means confined to those originated by the Department of Agriculture. Large numbers of cases were recorded in Bulletin No. 163 of the Bureau of Plant Industry, entitled "Varieties of American Upland Cotton," published in 1910.

Even when no attempt is made to conceal the fact that a new name represents only a special stock of a well-known sort, the change of name still carries an idea that some definite difference exists or is claimed. It is to be recognized, of course, that definite variations may be found in any variety, plants that are distinct from the parent stock, and that new names are required if these distinct forms are separated, bred into varieties, and placed in cultivation. But it is a mistake to suppose that novelties are of value as such or that frequent and indiscriminate introductions of new kinds are desirable. When a really new variety is to be established in cultivation, many experiments are needed in different parts of the country to determine the cultural characters and adaptations of the new sort, as well as the textile quality of the fiber. From the practical standpoint the claim of novelty is not to be made lightly, since in many practical ways it is a handicap to a variety to be new and untried. A period of years is required before the handicap can be removed by the practical experience of growers and a regular demand established with a basis of intrinsic value instead of mere advertising claims.

Though it doubtless is better to sell good seed under a new name than to send out an inferior stock merely to have something new to advertise, really good seed of a well-known variety should be considered more valuable than any new and untried sort. As soon as the possibilities of preserving and utilizing varieties are understood, the demand for uniform well-selected stocks of seed of established varieties undoubtedly will be greater than for new kinds of cotton.

Organized communities will not change varieties until definite advantages have been shown to justify a change by the whole community instead of by individual farmers. Intelligent communities will very properly avoid any new variety that does not come from a responsible source, well authenticated and with a definitely determined commercial status. The danger to the industry and loss to the farming public that result from introducing inferior varieties, or even too many good varieties, are being recognized in Egypt, in a proposal that has been made to license the introduction of new varieties and thus keep irresponsible parties from distributing undesirable sorts.

COMMUNITY PURE SEED THE BEST.

With one variety properly isolated and selected under local conditions, the seed not only can be kept pure and uniform but is likely to give better results than any seed that can be obtained from other districts. The degeneration that results from the crossing of different varieties no doubt is the basis of the popular idea that cotton varieties soon "run out" and that "fresh seed" must be brought from other districts. Though selection must be maintained to preserve a high degree of uniformity in any stock, deterioration is much more rapid if crossing takes place. The progenies of hybrid plants show large numbers of inferior individuals that are the most conspicuous evidence of degeneration. In this sense varieties undoubtedly "run out" with rapidity, depending on the extent of crossing that takes place.

The well-known fact that some of the best and most popular varieties have been grown for many years in the same place should be sufficient in itself to discredit the idea that degeneration of varieties is inevitable or to be expected in a few seasons. The well-known "Triumph" cotton, bred by Mr. Alexander Mebane, of Lockhart, Tex., has been maintained for 28 years by continued selection of the same stock, as stated personally by Mr. Mebane at a meeting of South Texas cotton growers at Corpus Christi on October 16, 1920.

Yet the superstition of "changing the seed" is widely current in the cotton industry and continues to be propagated by seed dealers as well as by owners or managers of gins and oil mills, who often sell carloads of "fresh seed" to the farmers of the surrounding community, regardless of the fact that bringing more kinds of seed into the community only widens the range of mixing that goes on at the gins and the crossing in the fields. No matter how good the "new" seed may be, there is no hope of retaining the uniformity of any select stocks that may be added to the general mixture. The only prospect of having a good variety to use is by united community

action for cleaning out the mixed seed and then maintaining a pure stock. As long as isolation is maintained the varieties are preserved with no evidence of "running out" that has anywhere been established on a basis of scientific credence. The districts that produce the good seed do not change their varieties, but continue to furnish the same seed for those who believe that "seed must be changed."

The idea formerly entertained that cotton is not cross-pollinated or that crossing is very infrequent and not of practical importance in relation to seed supplies has proved to be erroneous. Although cotton pollen is not blown about by the winds, because the grains are sticky and adherent, the pollen is carried commonly for considerable distances by bees or other insects that visit the flowers, so that varieties growing in neighboring fields are cross-pollinated, in addition to the general crossing that takes place in fields where mixed seed is planted.

Apart from the results of mixing and crossing, no real basis of natural law, reason, or necessity for the supposed rapid deterioration of seed or for the shipping of seed about from one district to another has been demonstrated in connection with cotton. After long periods of years it may be that varieties will deteriorate, decline in fertility, or become more susceptible to disease in spite of careful selection being applied, but at least it has to be recognized that such eventual deterioration, if the fact were established, would be quite distinct from the "running out" through the crossing and mongrelizing of different sorts that are grown and mixed together.

Mongrelizing is a result of careless handling of varieties instead of being a defect or a disease. The supposed remedy, "changing the seed," does not remove the cause of degeneration, but only invites more "running out." The more numerous the varieties represented in a community, the greater the mixing of the seed at gins and crossing in the fields. Instead of "change of seed," the methods of obtaining the seed supply need to be changed, so that varieties can be preserved and kept uniform instead of being mixed and allowed to deteriorate. No matter how good the original varieties may have been, a mixed stock becomes, in a few generations, thoroughly miscellaneous and mongrelized, with many abnormal and infertile plants, very inferior to the parental types.

Once the belief in rapid "running out of varieties" is abandoned, the supposed need of a continual succession of new varieties may give place to a stable system of production, with no casual changing or mixing of varieties. A variety that is once established in cultivation should continue in use until a better is definitely known and adequate supplies of pure seed are provided in advance, so that whole communities at once may secure a new basis of production.

Stabilized community production of the best variety that can be grown under the local conditions is the ideal that should not be sacrificed to curiosity or casual interest in untried novelties, even though vividly advertised. Testing new sorts is important, of course, so that no really valuable improvements may be overlooked, but not many farmers can observe the precautions that are necessary to secure definite determinations of relative values of varieties. Even the agricultural experiment stations find this a difficult problem, requiring several years to reach reliable results. Seed from test plantings is worthless, on account of the crossing that usually takes place, so that the experimental farmers often injure their own crops. When the real issues are understood, a farmer who plants an unknown variety of cotton will be considered as erratic as one who would raise a dangerous weed in his garden or try casual experiments with foreign pests or diseases.

To begin a new community, the best seed that is obtainable should be brought in from some district where selection and isolation have been maintained to guard the purity and uniformity of the stock. With the same precautions continued for a few years under the local conditions, the home-grown seed is likely to be found distinctly better than any that can be had from other districts. A special value is indicated for selection under local conditions in giving a better adjustment or more uniform expression of the desirable characters of a variety, in contrast with the greater variability that often is shown in stocks that are planted for the first time under new conditions. Experiments show that selection for local adjustment is needed to render the varieties more fully adapted to the local conditions, as indicated by the fact that larger yields have been secured from locally selected strains than from seed of the same varieties brought from other districts in cases where careful comparisons are made. Further examples of local adjustment have been published recently from experiments in North Carolina and Mississippi.[6]

DIFFERENT KINDS OF ORGANIZATION.

Many different forms of organization may be expected to develop to serve various local needs under the general purpose of community improvement of cotton production. Large properties that have their own gins and handle their seed stocks carefully may establish one-variety community conditions by adopting this as a principle of management, or neighboring estates may adopt such a policy and make it effective through ownership or control of a

[6] Brown, H. B. Why not plant home-grown sotton seed? *In* Prog. Farmer (Miss. Valley ed.), v. 36, no. 14, p. 391. 1921.

gin. Formal organization may be unnecessary if agreement can be made effective in other ways.

The problems of marketing have become acute in recent years and have the public attention as never before, but this interest should not detract from the importance of improving production, which gives a better basis for improvement than any other feature of the industry. For marketing reasons alone it might be urged that communities should grow only one variety, because better prices can be secured for large quantities of one kind of fiber than for small quantities of different kinds, but other reasons for community cooperation lie strictly in the field of production. Some economists treat marketing as a community problem, in contrast with production as an individual problem, but this distinction is hardly to be maintained in the cotton industry. Certainly there are market advantages to gain through community organization, quite apart from any effort to improve the crop, but the community factors of production are equally distinct and should not be confused in practical thinking. Organization for the improvement of production may serve important purposes and yet be kept entirely distinct from marketing organizations.

Community production does not mean that the individual farmers are any less responsible for the careful handling of their crops, but the underlying conditions of production are improved. With better varieties grown and better methods used, better results can be secured from all the farm operations, as well as in the marketing of the cotton at the end of the season.

Planting only one kind of cotton in a community is a very simple and practicable improvement that benefits all the farmers and all the business men of an organized community and injures nobody. As soon as pure seed is available for the entire community, production advances to a higher plane. The only serious obstacle that interferes with a rapid extension of this elementary improvement is that the facts are not known widely and intimately enough. The farmers themselves, and even the leaders of agricultural progress, are not sufficiently aware of the practical importance of good varieties of cotton, nor of the precautions of isolation, separate ginning, and continued selection that are needed to maintain the purity and uniformity of the stocks. Many progressive farmers would be ready to take these precautions if they could be assured that practical advantages would be gained, and such assurances become possible when one-variety conditions are established.

Advantages of community cooperation in the marketing and through bringing together larger quantities of cotton are being demonstrated by the Bureau of Agricultural Economics. Cooperative marketing communities have been organized in several States,

and assistance is given by the bureau mentioned in grading and classing the cotton, to furnish a basis for more direct dealing in large lots with responsible local buyers or with outside purchasers. This tends to stimulate competition, and it has been shown that buyers will come from long distances if sufficiently large stocks of cotton are offered. Moreover, the chance of securing a large lot of one superior kind of cotton is more of an attraction to an outside buyer than the same number of bales made up of different varieties or raised from mixed "gin-run" seed. The following statement, published in the News Letter of the Department of Agriculture for August 10, 1921, gives an example of the results that have been secured in some localities by cooperative cotton marketing:

Texas Growers Benefit Through Pooling Cotton.

How demonstration work in cooperative marketing is aiding farmers during the current season is illustrated by the story of a pool formed in Texas, as reported by the Bureau of Markets and Crop Estimates of the United States Department of Agriculture.

Three hundred bales of cotton were placed in this pool. Individually the growers had been offered from 3 to 7 cents a pound for the cotton on their local market. The entire lot was classed by representatives of the Federal bureau and grade cards issued to the owners. The samples were then forwarded to Dallas and the cotton trade invited to bid. The lot was sold at 10.25 cents a pound average.

On the classification made by the bureau's representative the pool averaged 75 points off middling. The middling spot price at Dallas on the day of the sale was 10.35 cents. The growers' accounts were settled on the basis of the grade cards issued for the individual bales, using the Dallas differences for the day.

In unorganized communities the farmers who raise better cotton than their neighbors usually are forced to sell at the same price to the local buyers. Manufacturers pay more for high-quality fiber, but the difference is absorbed by the buying trade instead of being shared with the farmers. The more valuable bales contribute to the profit of buying and sorting over the miscellaneous "hog-round lots" accumulated by local buyers, many of whom do not know how to "class" the cotton. Where this condition exists, so that farmers have to sell their cotton at the same price without regard to the quality of the staple, the only object in choosing varieties is to get large yields. Some of the most inferior varieties, with short, weak, and irregular lint, yield well and are grown in large quantities simply because the commercial system fails to apply any adequate discrimination of quality in buying the cotton from the farmers.

Failure to give the farmer practical encouragement in his effort to improve the crop is a serious defect of the present commercial system, but organized communities have a standardized product, better than any of the "even-running lots" that can be made by sorting and

matching the inferior fiber of mixed communities, so that the commercial problems are simplified. Even in advance of formal organization of communities a distinct advantage may be shown as the one-variety condition is approached. The general popularity of the big-boll type of cotton in Texas has kept the crop more uniform and given that State an appreciable market advantage in comparison with other parts of the Cotton Belt. Premiums of $10 to $20 a bale are being paid in Texas and Oklahoma communities because most of the farmers grow the Lone Star or Acala variety and the buyers compete for the superior fiber. Active campaigns for community standardization and marketing are in progress in Texas, Oklahoma, and North Carolina.

PROGRESS IN ORGANIZED COMMUNITIES.

One-variety communities are progressive in many ways that are beyond the possibilities of unorganized communities. With only one variety being grown, interest and emulation develop among the farmers, because they know that their results will come into direct comparison with those of their neighbors and will depend very largely on their ability to handle their crop in a skillful manner. Effects of different conditions of soils, seasons, and cultural methods are more clearly recognized in one-variety communities instead of being confused with differences in the characters of the varieties, and the farmers gain a more thorough, practical familiarity with the characteristics and behavior of the single type to which their attention is devoted.

No other cotton-growing district has made such rapid progress in recent years as the Salt River Valley of Arizona, where only the Pima variety is grown. The interest in the Pima cotton has been more acute and more constructive than would be possible if attention were divided upon two or more sorts. Cotton problems are discussed with interest and profit at farmers' meetings, because everybody is having experience with the same variety. Such progress is not possible in communities where different kinds of cotton are grown and farmers are accustomed to ascribe their success or failure to the seed that was planted.

With adequate understanding of the behavior of one variety, methods are adjusted more closely to differences of soils, seasons, and times of planting, and labor is applied to the best advantage in farm operations. In weevil-infested regions it is especially important that all the farmers of a community grow the same variety, plant as nearly as possible at the same time, handle the crop together, and clear the fields early in the fall. One-variety communities develop skill, while mixed communities suffer from backward

cultural methods as well as from deterioration of varieties through crossing and mixing of seed.

Experience with the one-variety plan during the last decade has shown that fundamental reforms in the system of production are possible through community organization. The product of organized communities is more uniform, not only because pure varieties are grown but because the cultural treatment is better. The crops are larger and the product more valuable on account of the longer and more uniform staple. The relation to markets is altered as profoundly as the relation to production. In addition to having a readily standardized "unit" product to offer, a genuine community of interest among the producers enables them to deal more constructively with each of the problems of handling the crop. The many new problems that one-variety communities have encountered is evidence in itself that a new basis for constructive effort has been attained. Many undertakings that were entirely beyond the scope of the individual farmer become practical possibilities through community cooperation. At every point of difference the one-variety communities have the advantage over the mixed communities.

One effect of the system of buying is to keep the producing and manufacturing interests apart, out of the range of constructive relations. Though the manufacturers want better cotton and in larger quantities, there is no provision for encouraging the production of better fiber. The commercial system acts rather as a nonconductor between the factory and the farm. As long as the crop is altogether miscellaneous in character and quality and the commercial system remains as it is, there is little prospect of developing the just discrimination in prices that is needed to stimulate improvement of production. The progressive farmer who produces better cotton than his neighbors has too small a chance of getting a better price for his crop.

Discontent or dissatisfaction of farmers with the commercial system leads to many efforts to eliminate or reduce the exactions of the "middleman" through legislation or other restrictive measures, but the need of improving the system of production has not been appreciated. Commercial improvements might become more feasible if the product could be more definitely standardized and its value more definitely known to the farmer as well as to the buyer and the manufacturer.

Merely "cutting out the middleman," as the saying is, would not solve the commercial problem in relation to production. The manufacturers are not in position to buy directly from individual farmers or to see that progressive individual farmers are paid full prices for the few bales of good cotton that such farmers may produce,

scattered about in mixed-variety communities. Assembling, sorting over, and classing the American cotton crop is an expensive operation which unified community production would greatly simplify.

Without discussing the question whether the buyers generally get too large a return for their services in assembling and sorting over the crop to make up the commercial lots that manufacturers buy, attention may be called to the fact that the work done by the buyers in classing and assembling individual bales of the various qualities and conditions of fiber to make up the "even-running" commercial lots would be greatly facilitated if the crop were standardized in production through one-variety community organization. Thousands of men are employed and millions of dollars expended every year in sampling, sorting out, and assembling commercial quantities of the different qualities of cotton before selling to the manufacturers, and much of this effort and expense could be avoided if communities grew one uniform kind and handled their product in a uniform manner. The preliminary for unifying and standardizing the quality of cotton is the planting of uniform seed and giving equal conditions and care to the growing plants, so that regular development may follow and normal maturity may be reached.

Even if the manufacturers were in position to take over the whole system of buying, classing, and sorting the crop, community cooperation would still be necessary for effective improvement of production. On a community basis the buying and other commercial problems are simplified, as shown by the experience of one-variety communities.

CLASSING COTTON IN THE FIELD.

On account of the use of cotton fiber for machine spinning there is a particular requirement that the cotton grower's product shall be uniform in order to be of good quality for manufacturing purposes. Mixtures of long and short staples are worse than useless to the manufacturer and can be sold by the farmer only because unskillful buyers may fail to detect even badly mixed fiber. The simplest and most definite way to detect mixing is to inspect the plants in the field. If a farmer's cotton is not uniform its quality is already impaired. It is impossible that really first-quality fiber should come from a mixed field. Even with short staples uniformity is important, and manufacturers would willingly pay more for really uniform fiber if assured of the "even-running quality" that is their ideal of textile raw material. Notwithstanding the importance of uniformity to the manufacturer, little attention has been given to this problem on the side of production.

The quality of cotton, and especially the uniformity of the fiber, can be judged much more effectively in the field than by the present

system that looks for quality only in samples taken from the bales. By simple inspection of the fields it is easy for those who are familiar with varieties to see whether the plants are all of one kind, or of two or more different kinds, or a miscellaneous mixture of sorts as in the ordinary "gin-run" stocks. If the plants are different and produce different kinds of fiber, the staple will not be uniform in the bale, though it is much more difficult to detect the mixture of different kinds of fiber in the bale than to recognize the different kinds of plants in the field. It is known in long-staple markets that buyers commonly overlook mixtures of 10 or 15 per cent of short staple. Some unscrupulous farmers make a practice of mixing short-staple seed with long-staple Upland varieties and find that even 50 per cent of short cotton can sometimes be sold at the price of long staple, so inadequate is the present system of buying, on samples from the bales.

The true community of interest of the growers is most obvious from the standpoint of production, and practical local organizations would form the most effective connection between the individual farmer and any general organizations that were regularly maintained.

That farmers fail so often to secure fair prices for their cotton under the present commercial system can be charged, in part at least, to the chaotic conditions which tend to keep the farmers from knowing the true quality or value of their cotton, whether bad or good. The entire responsibility of selecting and standardizing the farm product is thrown upon the buyer or upon the commercial system, instead of the standardizing being done on the farm, which becomes possible in one-variety communities.

One-variety communities not only avoid the mixing of seed but are in position to take another important step in standardizing the quality of their cotton by recognizing the effects of different conditions of growth. Pure seed is essential for a uniform product, but favorable conditions of growth are also necessary in order to attain a regular, normal development of the crop. If the soil or the other conditions are adverse, so that the plants fail to grow or are forced into rank growth and then checked by drought or other unfavorable conditions, fiber of very irregular quality is produced. To maintain a continuous normal development of the plants without forcing or checking is the problem of skillful cotton farming.

Farmers of the irrigated districts who leave their cotton too long without water during the heat of the summer not only may cut their yields to half a crop but at the same time impair the quality of the fiber to an equal or greater extent. Bolls do not reach normal development during the water-stress period. The seeds do not grow

to full size, and many have abortive, shriveled embryos, while the fiber is both shorter and weaker than that of the normally developed bolls. Parts of the same field or the earlier or later bolls on the same plants may grow to full size and produce good fiber, but the crop as a whole is inferior. The mixture of weak "perished" fiber from the shriveled, poorly developed bolls impairs the textile quality as definitely as a mixture of short cotton unless the damage is avoided by picking the injured cotton separately. Cotton that develops under uniformly favorable conditions not only yields more but the fiber is of much higher textile value, which undoubtedly would be recognized in the market if a more practical system of buying were developed.

Field-inspection buying could be used to advantage even in mixed-variety communities, to avoid the worst and most uneven stocks or fields injured by unfavorable conditions, but the crop could be much more effectively standardized in one-variety communities, on account of the greater familiarity with the chosen variety and easier and more definite recognition of its characters and behavior. The general tendency of such a system would be progressive in relation to varieties and to careful growing of the crop. Not only the farmer who planted low-quality or mixed seed could be detected and avoided by buyers, but the differences that result from cultural conditions could be recognized in classing the cotton. Organized communities would be able to get the full value of the more uniform fiber that they are able to produce, in addition to the other advantages of using superior varieties.

RELATION OF COMMUNITY PRODUCTION TO DIVERSIFIED FARMING.

Community organization to maintain production of the same kind of cotton from year to year gives a better basis of developing a well-balanced system of agriculture. Regularity of production and uniformity of product are fundamental factors in the utilization, market demand, and commercial value of an industrial raw material. Plunging from one crop or from one variety of cotton to another, so that one year there is a surplus and the next year a "cotton famine," is not properly to be described as diversification, but rather as "wild-cat" agriculture. No sort of cotton can attain its true industrial value without regularity of supply and the development of confidence by the industrial world that the same raw material is to be available from year to year in approximately the same quantities. In other words, stabilizing production, which is possible through community organization and in no other way yet suggested, would be an advantage to the industry, as clearly in the

interest of the manufacturer and of the commercial world as of the farming communities that would standardize their production and place themselves in responsible, constructive relations with the industrial world.

The tendency to speculative campaigns, or "booms," for exclusive or excessive planting of a crop that seems promising is especially strong in the southwestern valleys where new lands are being developed and new crops are being sought to get the high returns that are necessary to meet the cost of irrigation works, leveling the land, and other improvements. Under these conditions stronger tendencies to intensive industrial developments of agriculture are to be expected, away from the older forms of diversified farming that were based primarily upon supplying the needs of the family instead of producing a commercial crop. Instead of expecting a return to more primitive systems of diversified farming, of which there is little prospect in the irrigated valleys, the hope of future progress seems to lie in the direction of balanced systems of production, grouped around special, highly developed industries which receive primary attention as the main source of the farm income. If the chief money crop is to be cotton it is all the more important to hold to one type and variety, so that the quality may be maintained, the culture perfected, and the relations to other crops definitely adjusted.

A suggestion has been made in Arizona and California that community local-option laws might be passed that would make it possible for the farmers of any locality or district to establish the culture of a single variety and secure legal protection against the planting of other kinds of cotton, to the detriment of the community. In the Southwestern States the legal recognition of organized cotton communities would follow the analogy of the system that allows the farmers to organize themselves into irrigation districts, take responsibilities for building dams, canals, or other improvements, and assess the costs against the lands that are in reach of the water supply. Other analogies may be found in the laws that have been passed in many States for controlling weeds, plant diseases, and insect pests or for abating nuisances of other kinds.

There can be no question of the injury that would be suffered by farmers who have established pure seed supplies of a superior variety of cotton if a careless, ignorant, or malicious neighbor should plant an inferior variety or mixed stock. This not only would destroy the value of the surrounding fields for pure seed, but would impair the seed and quality of fiber of the whole community if the inferior seed were taken to the public gin. The underlying principle of such regulations is to assert the right of the community to agree upon and carry through such general community improvements. A system

that allows communities to maintain and utilize superior varieties of cotton has a very close analogy with provisions for carrying through other public improvements, such as roads, drainage, or irrigation works, instead of allowing such progress to be hampered or prevented by careless, backward, or perverse individuals, who may be found in small numbers in any community.

INTEREST IN COMMUNITY DEVELOPMENT.

Progress in cotton communities is not to be expected from external influences or from organization alone, but it depends on local interest inspired by practical understanding and a right public spirit or community point of view. Merely to recognize the advantages of the one-variety plan is not enough. The successful working out of any local application of the plan depends upon the constructive interest and initiative of the community itself, in the same way that the individual farmer must have an active and progressive interest in adopting a cultural improvement, which otherwise he will fail to understand or to use properly. Experience with community work in other places can be utilized, but communities differ no less than climates or soils, and measures of progress have to be adapted to local community needs and developed mainly through local interest and initiative.

That community conditions are so varied and that some communities are so much more ready than others to take up and carry forward such a plan as one-variety organization of cotton production make it the more important to have the plan widely known among agricultural leaders of the cotton-growing regions, whether official or private, so that the most favorable conditions for community development may be found. From this standpoint the improvement of the cotton industry is no longer a merely biological or breeding problem, limited to the technical plant characters, cultural methods, or industrial requirements, but also has a general social or sociological side. Methods of organizing cotton-growing communities need to be devised, studied, and gradually perfected, like methods of organizing industrial corporations, irrigation districts, or other special forms of cooperation.

That pure-seed problems should be considered by sociologists would not be expected, or that plant breeders should study community organization, but there is a common ground of interest and practical cooperation. Breeders of varieties must learn the value and need of community cooperation, while sociologists and economists, as well as teachers and agricultural leaders generally, should take more account of the biological factors that determine the improvement or degeneration of varieties. To devise effective methods of organiz-

problem, limited to the technical plant characters, cultural methods,

ing and conducting the activities of one-variety communities in growing, handling, and marketing the crop and in maintaining the purity and uniformity of the basic stocks are problems of as much practical importance as the original discovery or breeding of the varieties and equally worthy of careful, scientific study, as well as of being popularized and made available for general use.

If the utilization of varieties depended upon finding a new chemical to treat the seed or to fertilize the soil or upon devising a new machine for planting, cultivating, or harvesting the crop, the problem would appear normal, and a solution could be sought along the usual technical lines, but the social factors of community organization need to be considered as well as physical conditions or mechanical operations. The community conditions are equally fundamental, since superior varieties of cotton can be utilized only as they are kept uniform and apart from other varieties. Except through community action there seems to be no prospect of approach to a general application of the science of heredity or the art of plant breeding in the improvement of the cotton industry.

As experience has shown, very intelligent people may fail to understand the essential nature of such an undertaking as one-variety organization of cotton communities. Some are inclined to oppose any form of cooperative effort as "wasting of time and interfering with business." Others may admit the desirability of community organization, but still may not appreciate the fundamental difference in relation to production, that organized communities have good seed to plant while unorganized communities do not. Though the farm operations in one-variety communities are not united but remain as strictly individual as before, the quality and efficiency of farming are improved because knowledge and interest are focused and specialized, with more of a public or social interest to stimulate expression and communication of ideas among the members of such communities.

Since it is an advantage to each farmer that his neighbors also shall plant good seed and raise good crops, there is a basis for a regular, continuous growth of constructive community interest. A community spirit and even a community mind must develop, in order to have consistent and unified community action sustained through a period of years and eventually recognized and established as a normal condition of cotton production. It is a mistake to suppose that the problems of community development are to be solved merely by acquiescence or by getting a majority vote in favor of the one-variety plan. An effective preponderance of public opinion must be established and maintained, and this calls for clear understanding and active interest in the progress of the community as well as in the problems of the cotton industry.

The first problem is to get the general facts that determine the need of organization as clearly understood as possible. Until the need of unified community action is recognized, the interest is likely to wander at any time to other phases of the subject, and even the most incidental. Though many communities would find serious difficulties in reaching an agreement to grow only one variety of cotton, some communities are ready for the step, with the necessary interest and leadership, to enter upon an active course of improvement. Hence, the plan needs to be brought to the attention of those engaged in the investigation of general problems of public welfare, in order that more of the public-spirited interest of active communities be enlisted. On account of these considerations, the improvement of the cotton industry ceases to be merely a botanical or biological problem of discovering new varieties or maintaining select strains and takes on a sociological aspect, to learn how communities should be organized for more effective application of the scientific factors of production.

Leadership undoubtedly is necessary in cotton-community development, as in other forms of social progress, and very patient constructive leaders are needed in cotton communities, at least in the early stages of development, while the farmers are still only partially aware of the needs and possibilities of one-variety organization. Communities in this stage of development may be affected adversely by too much activity, or "drive," on the part of their leaders if a sense of cooperative responsibility is not developed and the local public does not become actively interested and well informed regarding the objects or measures that the leaders may urge. A passive, indifferent community is the more open to groundless suspicion of some private advantage being sought by those who are urging improvements and is ready for obstructive or adverse suggestions. It is to be expected that some elements in each community will consider it a virtue to oppose anything that is being "put across." Hence, the interest of the community must be kept so clearly to the front that it shall not be confused with personal or incidental issues of other kinds.

Not to enlist all of the local interest and constructive ability is to forfeit in advance the hope of getting the best possible results from a community undertaking. Even partial success may have great practical value, but people will go farther if they can believe that the very best is being done and that all of the available talent is being applied to a full understanding of the problems. To know that important practical problems are being worked out, that fundamental reforms are in progress, to which their own community thought is contributing, stimulates interest and constructive effort,

not only in relation to cotton production but in other possibilities of improvement that need to be viewed from the same standpoint of adapting our agricultural activities more fully and effectively to our present state of progress.

The outcome to be expected is that a new association of ideas may develop and become firmly established in the minds of farmers, so that they will think not only of having good seed and raising good crops on their own individual farms but will have an equal appreciation of the practical importance to them of the progress of the community as a whole. To the motive of local patriotism that often is urged for adopting improvements, there is added the direct interest of each farmer in the quality of the community product as a whole, since each farmer stands very clearly to get more for his cotton and to have a better assured market for future crops if his neighbors are also raising the same kind of cotton and the quality of the variety is being maintained. An established reputation and assured market for a staple product are practical assets for a community, tending to increase the value of property and encourage public improvements.

In communities that are not yet united for constructive work it is better to place the first emphasis upon the general advantages of one-variety organization rather than to insist upon the superiority of a particular kind of cotton. It often is not possible to say which variety is the best that can be had. Choice of varieties is limited generally by the fact that stocks of pure seed are obtainable for only a few kinds. The first one-variety communities in each district will profit especially by selling seed to other communities, which is an immediate advantage in the early years of community development, before the marketing and other features have had local demonstrations. This consideration naturally will get preference for varieties that have good prospects of general use, as distinguished from those that require special conditions or are not widely known. Pure seed often sells as readily in carload lots as in bushels or tons.

Local experiments may be needed before the variety question can be settled, and seasonal fluctuations of behavior may be very misleading, so that several years may be required to reach definite results. But even a poor variety will give better results with community handling than good varieties mixed together. An organized community can change promptly to a superior variety when a definite advantage can be shown and seed can be obtained in sufficient quantity. The Pima variety was substituted for the Yuma in the Salt River Valley, Ariz., in the season of 1917, after a sufficient stock of seed had been raised to plant the entire acreage.

COMMUNITY UTILIZATION OF VARIETIES.

Considering that adequate supplies of pure seed are the first requisite for extending the use of any superior variety of cotton, it follows that any good variety must have a central localized production at first, whatever the later developments. This is especially necessary with varieties developed by the United States Department of Agriculture, which have a serious handicap at first in the seed being distributed free instead of going out as high-priced advertising novelties, sold very often at several dollars a bushel. Distributing the seed widely does not increase the supply, since little reliance can be placed upon seed that is raised by individual farmers in mixed communities unless special precautions of isolation and separate ginning are taken. The fate of most varieties is that they are not localized sufficiently to keep the seed pure, so that the scale of commercial production is scarcely reached before the variety begins to deteriorate. Hence, varieties of cotton are "short lived" unless a basic seed stock is preserved by continued isolation and selection. A variety no longer exists in a practical sense when uniformity is lost and the work of selection undone. The only varieties that have been useful are those that have been maintained for periods of years, in most cases by the original breeders, who established centers of production and seed supply in their surrounding communities through the practical inducement of buying or helping to find markets for the seed that their neighbors produced.

Localization of varieties in this necessary and constructive way is more common in Texas than in any of the States to the east, possibly because the boll-weevil invasion reached Texas first and there has been more time for readjustment. Another reason is that the eastern Upland varieties are not well adapted to the Texas conditions, so that the farmers have learned to depend on their local varieties instead of bringing seed from Georgia or the Carolinas, as the custom formerly was. Holding to the big-boll type of cotton has rendered the Texas crop generally more uniform, and a distinct market advantage is now recognized as a result. Although only a few communities have as yet undertaken a strict adherence to a single variety, the fiber quality and staple length of the Texas big-boll varieties—Triumph, Lone Star, and Rowden—are not so different as many of the varieties that are grown in other parts of the country, so that the Texas crop as a whole is of more uniform quality. But now it is being recognized that this advantage can be increased by more definite local specialization, and many Texas communities and districts are approaching the one-variety status.

In view of the requirement of seed supplies to make utilization possible, it is obvious that any variety which attains prominence and

holds its standing through a period of years must have somewhere a local base, where continued interest exists and precautions of selection and isolation are applied to keep up the stock and maintain the supplies of good seed. Local adoption and popularity of a variety, to the extent of having it planted by many neighboring farmers, is necessary for the development of a select stock to the scale of commercial production. Hence, such a nucleus or life center may be looked for with any variety of note. The town of Lockhart, Tex., has wide agricultural fame as the home of Triumph cotton, the most prominent variety of the Texas big-boll type, bred and maintained for many years by Alexander Mebane. A similar distinction is enjoyed in South Carolina by Hartsville, in Darlington County, as the center of production and seed supplies of the Columbia, or "Webber," variety. This was bred originally from Russell's Big-Boll by Dr. H. J. Webber, while connected with the United States Department of Agriculture. The first distribution of seed of Columbia was in 1907. The importance of the work of D. R. Coker in maintaining the seed stocks and establishing market relations for this new type of Upland long-staple cotton has been recognized in several publications of the United States Department of Agriculture.

The original home and center of seed supply of the Trice variety were around Jackson, Tenn., where the variety was bred by the late Prof. S. M. Bain, of the Tennessee Agricultural Experiment Station. The first distribution was made in 1909, after several years of careful selection and isolation of the stock. That these varieties and others have tended so strongly to remain localized and the seed supplies restricted, although well adapted to cultivation over large regions, is in itself an evidence of the need of giving attention more directly to the utilization and seed-supply problems.

A general plan of community cotton improvement has been followed for several years by the North Carolina Department of Agriculture and has been very successful in assisting farmers to appreciate the value of good varieties and good seed. A policy of first narrowing down to a few good varieties has been followed, as leading gradually to an appreciation of the practical advantages and advisability of using only one variety in a community. Local variety tests are conducted to enable the farmers of a community to select what they consider as the best from a series of promising varieties. Some communities have narrowed down to two or three varieties, while some keep four or five varieties in cultivation, but the number is being reduced every year.

The need of standardizing on the production of one variety is realized, and in Edgecombe County, in the east-central part of North Carolina, a general organization for planting a single variety has

been perfected recently. According to recent information from Prof. C. B. Williams, 58 communities have been organized in different parts of the State, and marked improvements in the crop are reported. A general report of the community work published in 1920 states that an average increase of $28.97 per acre over a period of five years was obtained from the use of the selected varieties instead of ordinary gin-run seed. An estimate of $41,000,000 is made in an article by F. H. Jeter in the Progressive Farmer as the amount that would have been added to North Carolina farmers' bank accounts if they had all used the varieties of cotton best suited to their needs.[7]

Although distinct and valuable progress undoubtedly can be made by getting farmers to plant good seed and discard inferior stocks, even without adopting the one-variety plan, it nevertheless is plain that the full objects and possibilities of improvement will not be attained. Testing varieties of cotton to determine which is the best for any locality is not easy, on account of the wide fluctuations of seasonal conditions and behavior that must be taken into account before a reliable conclusion can be reached. Even with only two or three varieties in a community many precautions of isolation and separate ginning must be observed. Ginning difficulties are reduced by having certain days to gin the cotton of the different varieties for seed purposes, but thorough cleaning of the gins requires time and labor. Even with the best intentions both the cotton and the seed are likely to be mixed somewhat unless very careful and persistent attention is given. Without these precautions there is the necessity of obtaining new seed of the popular varieties every two or three years. Not only are these difficulties to be avoided by community organization, but one-variety communities are able to sell seed instead of having to buy new stocks frequently.

PIMA COTTON COMMUNITIES.

The oldest and best established one-variety community is in the Salt River Valley of Arizona, where the Pima variety of Egyptian cotton is grown exclusively. The nature of this development needs especially to be understood because of the efforts that have been made to repeat the successes of the Salt River Valley merely by taking the seed of the Pima variety to other districts, without understanding the one-variety plan that has made it possible to establish the new industry in Arizona and that the same plan may be of value even beyond the range of the Pima variety. Experiments have shown that the Egyptian type of cotton is much better adapted

[7] Jeter, F. H. Your community's cotton reputation. How some communities are building good cotton names and capitalizing them. *In* Prog. Farmer, v. 36, no. 5, p. 358. 1921.

A new Acala community has been organized recently in the Coachella Valley of California, for the dual purpose of raising a uniform product and developing large stocks of pure seed to supply other irrigated valleys or for shipment to Texas or other eastern States in seasons of crop failure or scarcity of planting seed, as in 1920. Interest has been attracted especially by the fact that very large yields, at rates between 2 and 3 bales per acre, were obtained in the season of 1920 from two small plantings of Acala cotton grown at the Government date garden, about 2 miles west of Indio.

The cotton growers in the Coachella Valley have organized into an association, and the seed grown at the Government date garden is to be used as the basic stock. The date-garden plantings were well isolated and ginned with every precaution to avoid any admixture with other varieties, and another stock of good Acala seed was obtained from an isolated planting near Bakersfield, Calif., so that there should be no occasion to plant any other kind of cotton in the valley. The best of the Acala seed is planted on isolated fields, away from any other variety of cotton or from fields that have grown cotton recently. Arrangements have been made to have one gin reserved exclusively for Acala cotton.

On the basis of such precautions it is expected that seed raised in the Coachella Valley may have special value for planting purposes, not only for local use but for shipment to other cotton regions that do not have good planting seed. The cooperation of the Department of Agriculture of California is being sought by the Acala association for inspecting the fields and certifying the quality of seed, with such assistance as can be given by the United States Department of Agriculture in roguing and selection work. Thus it may be possible to develop in this valley, isolated from other cotton-growing districts, an Acala seed stock of the highest quality.

COMMUNITY UTILIZATION OF LONE STAR COTTON.

The Lone Star variety, representing the Texas big-boll type of cotton, somewhat similar to Triumph, or Mebane, and Rowden, is now grown very extensively in Texas and adjacent States, and even as far east as North Carolina. The Lone Star seed supplies have been centered chiefly in northern Texas, and especially in Hunt County, around Greenville. A field station has been maintained for several years at Greenville by the United States Department of Agriculture for the study of breeding and cultural problems of cotton.

On account of the superiority of the fiber of the Lone Star cotton, which often attains a length of $1\frac{1}{8}$ inches under favorable conditions, and often brings a premium of 2 or 3 cents a pound, and sometimes more, the Lone Star communities have important ad-

vantages. For Hunt County alone it was figured several years ago that replacing other varieties with Lone Star increased the returns to the farmers by about $700,000 in a single season.

The importance of maintaining and utilizing the variety by keeping up the supplies of good seed is so well appreciated in the community of Greenville that a tract of 60 acres of typical black-land soil was secured and made available for the use of the seed-breeding station, under cooperative arrangements with the Chamber of Commerce of Greenville.

Selection of the Lone Star variety is being maintained on the basis of pedigreed progeny stocks, with the cooperation of many farmers. Owners of the farms surrounding the seed-breeding station have agreed to plant only the Lone Star cotton or some variety recommended by the station, so that the basic stocks of the variety can be protected from contamination.

Another center of Lone Star seed production is being developed in southern Texas, around Tivoli and Austwell, in Refugio County, north of Corpus Christi, with precautions of continued selection, roguing, isolation from other cotton, and separate gins where this variety is handled exclusively. With these precautions extended over large acreages, high-quality planting seed can be made available in carload lots to other districts.

In the spring of 1920, after all the stocks of good seed in northern Texas had been exhausted, a carload of seed from Austwell was ordered by express for growers of the Lone Star variety around Greenville, in order to replant their cotton, which had been destroyed repeatedly by bad weather. In addition to the price of the seed, the growers paid $800, or 75 cents a bushel, in shipping charges to get the seed promptly and avoid the necessity of using inferior seed or sacrificing the crop. That the seed was obtainable in southern Texas appeared very fortunate, to avoid a still more serious impairment of supplies of good Lone Star seed around Greenville as a result of very bad seasons in 1919 and 1920. The lesson of such an emergency is that dependence should not be placed upon any single district to furnish all the supplies of good seed of any important variety, but many communities, preferably in distant regions, should maintain supplies of pure seed that can become available when needed.

CONCLUSIONS.

How to preserve and utilize superior varieties of cotton is a problem worthy of scientific study, no less than the methods of developing varieties by breeding and selection. In most of our cotton-growing communities varieties are not preserved or utilized properly and are subject to rapid deterioration as a result of frequent buying of new

sorts, mixture of seed at the public gins, and crossing of different kinds in the fields.

Varieties of cotton mongrelize rapidly through mixing and crossing, with a resulting loss of the uniformity of select stocks, small yields, irregular fiber, inferior textile quality, and lower market price. Such mixing and deterioration take place inevitably in all communities where different kinds of cotton are grown on neighboring farms and taken to the public gins, as is the general custom. Most of the farmers plant ordinary "gin-run" seed, a mixture of many varieties and mongrel, degenerate forms.

The popular idea that varieties of cotton "run out" rapidly and need to be replaced frequently by new sorts has as a basis of fact that degeneration undoubtedly is caused by the mixing of seed and crossing of the different kinds in the fields. No variety can be kept in a pure, uniform condition if selection and isolation are neglected. The only way to preserve a variety and develop a large stock of pure seed is to grow only one kind of cotton in a community, so that there is neither crossing in the fields nor mixing at the gins to destroy the effect of selection.

Since the usual conditions of mixed-variety production do not make it possible to develop stocks of pure seed of sufficient volume to provide for full use of a variety, exclusive community production of single varieties is a necessary precaution to maintain adequate stocks of pure seed for general planting over large areas. Community organization of production is the most effective way of utilizing superior varieties and of applying the results of scientific investigation of problems of heredity and breeding.

Wider utilization of superior varieties is needed, especially at the present time, in order to advance the quality of our cotton and avoid the competition that is being developed rapidly in foreign countries. Full utilization of varieties is not to be expected unless stocks of pure seed are maintained and increased for general planting over large areas. A very striking demonstration of the advantage of one-variety cotton communities has been secured in the Salt River Valley of Arizona, where only the locally selected Pima variety of Egyptian cotton is grown and now is represented by a larger stock of pure seed than any variety in the eastern Cotton Belt.

Manufacturers have complained for many years of a general and gradual decline in the quality and uniformity of American cotton, and this may be ascribed to the substitution of large public gins for the old system of private plantation gins during the half century since the Civil War. During the same period separately operated small farms and tenant holdings have taken the place of the larger plantation units of production, which doubtless has increased the

tendency to mixing and degeneration of varieties. But this tendency may be counteracted by organizing one-variety communities.

Though larger units are desirable, the practical minimum of organized production is the gin-unit community, to include all the farmers who take their cotton to the same gin. Separate ginning and isolation and roguing of seed fields is essential to organized effort for utilizing superior varieties of cotton. The mixing of different kinds of seed at the gins is the chief agency of deterioration of varieties, and must be avoided if other precautions are to be of practical value.

Except for the deterioration that results from the mixing and the crossing of different sorts there is no basis of fact for the popular idea that varieties of cotton run out rapidly or need to be changed frequently. With precautions of isolation, careful selection and roguing of the seed fields, and separate ginning, a variety of cotton can be kept pure and uniform and grown for many years. Production should be stabilized by the continued use of standard varieties. New sorts should not be substituted until their superiority is definitely shown and such seed supplies are available that whole communities can change at one time. It is wasteful of good seed to send it out to scattered individual farmers in mixed-variety communities where isolation and separate ginning are not provided.

Numerous varieties of cotton are unnecessary and undesirable both for agricultural and for industrial reasons. The commercial practices of introducing many new kinds or of renaming old varieties to meet popular demands are based on a misunderstanding of the facts and do not tend to improve production, but add to the mixture of the "gin-run" seed.

Though many varieties of cotton have been bred and distributed by the United States Department of Agriculture, only those are being maintained and extended on a scale of commercial production that have been adopted and centralized in communities so as to provide larger supplies of pure seed. Experience of nearly two decades has shown that the breeding and distribution of seed of superior varieties, either by the United States Department of Agriculture or by local or private efforts, does not result in any general improvement of production, because of the lack of any adequate system for developing and maintaining large supplies of pure seed. Studies of utilization and of seed-supply problems have shown no way to develop and maintain adequate supplies of pure seed of superior varieties and keep such seed supplies permanently available except in one-variety communities where the mixing of seed at the gins and the crossing of varieties in the fields are avoided.

Experience of several years in one-variety communities established in irrigated valleys of the Southwestern States has demon-

strated the practical value of the one-variety plan and the importance of extending it to other regions. Not only supplies of good seed but cultural improvements and marketing problems can be worked out to better advantage in one-variety communities on account of the better basis of production. More active interest and greater skill in the handling of the crop are developed when the attention of all the farmers of a community is directed to a single superior variety instead of being confused and dissipated by the presence of different varieties and inferior mixed stocks. Hence, a careful consideration of the one-variety plan may be urged upon those who are interested in any measures of improvement in the cotton industry. In view of the enormous wastes of the present system there should be no unnecessary delay in utilizing the varieties and other improvements that are possible and ready to be applied as soon as the farming public is sufficiently informed.

LIST OF PUBLICATIONS ON COMMUNITY COTTON IMPROVEMENT.

The following list includes publications issued by the Department of Agriculture and a few other papers that treat of improvement of the cotton industry through community organization, in order to utilize superior varieties and maintain pure seed supplies:

Cotton selection on the farm by the characters of the stalks, leaves, and bolls. By O. F. Cook. Bureau of Plant Industry Circular No. 66. Issued August 13, 1910.

Cotton improvement on a community basis. By O. F. Cook. Yearbook for 1911, pp. 397–410. See also report of the Chief of the Bureau of Plant Industry for 1911, p. 24.

Selection of cotton and corn seed on southern farms. By S. A. Knapp and J. A. Evans. Bureau of Plant Industry Document No. 747. (Farmers' Cooperative Demonstration Work No. "A"–67.) Issued May 11, 1912.

Factors affecting the production of long-staple cotton. By O. F. Cook. Bureau of Plant Industry Circular No. 123, pp. 3–9. Issued April 26, 1913.

Cotton problems in Louisiana. By O. F. Cook. Bureau of Plant Industry Circular No. 130, pp. 3–14. Issued June 21, 1913.

The relation of cotton buying to cotton growing. By O. F. Cook. U. S. Dept. of Agriculture Bulletin No. 60. Issued February 16, 1914.

Custom ginning as a factor in cotton-seed deterioration. By D. A. Saunders and P. V. Cardon. U. S. Dept. of Agriculture Bulletin No. 288. Issued September 7, 1915.

Community production of Durango cotton in the Imperial Valley. By Argyle McLachlan. U. S. Dept. of Agriculture Bulletin No. 324. Issued December 22, 1915.

Community production of Egyptian cotton in the United States. By C. S. Scofield, T. H. Kearney, C. J. Brand, O. F. Cook, and W. T. Swingle. U. S. Dept. of Agriculture Bulletin No. 332. Issued January 13, 1916.

Tests of Pima Egyptian cotton in the Salt River Valley, Arizona. By T. H. Kearney. U. S. Dept. of Agriculture, A. & D. R. P. Circular 1. Issued December 6, 1916.

Extension of cotton production in California. By O. F. Cook. U. S. Dept. of Agriculture Bulletin No. 533. Issued March 3, 1917.

Production of American Egyptian cotton. By C. S. Scofield, T. H. Kearney, C. J. Brand, O. F. Cook, and W. T. Swingle. U. S. Dept. of Agriculture Bulletin No. 742. Issued January 15, 1919.

Cotton improvement under weevil conditions. By O. F. Cook. U. S. Dept. of Agriculture, Farmers' Bulletin 501 (revised edition). Issued October, 1920.

Cotton a community crop. By O. F. Cook. Journal of Heredity. Issued April, 1920.

Commercial parasitism in the cotton industry. By O. F. Cook. Nature (London). Issued July 1, 1920, pp. 548–549.

Community cotton improvement in North Carolina. By R. Y. Winters, S. W. Hill, and P. H. Kime. North Carolina Agricultural Extension Service Circular 108. Issued September, 1920.

Your community's cotton reputation. How some communities are building good cotton names and capitalizing them. By F. H. Jeter. The Progressive Farmer. Issued January 29, 1921, p. 130.

The cotton variety problem. By J. S. Cates. The Country Gentleman Issued March 5, 1921.

Adelanto en el cultivo del algodón. By O. F. Cook. Boletín de la Unión Pan Americana. Issued March, 1921, pp. 273–294.

City and country. By O. F. Cook. The Journal of Heredity. Issued March and April, 1921.

Improvements in cotton production. By O. F. Cook. U. S. Dept. of Agriculture Circular 200. Issued November, 1921.

Cotton-seed mixing increased by modern gin equipment. By W. W. Ballard and C. B. Doyle. United States Department of Agriculture Circular 205. Issued February 17, 1922.

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THE WESTERN YELLOW PINE MISTLETOE:

Effect on Growth and Suggestions for Control.

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INTRODUCTION.

Western yellow pine (*Pinus ponderosa* Laws.) occurs naturally from southern British Columbia to northern Mexico and from the Pacific coast to east of the one hundredth meridian. It is found in the forests of every State west of the Great Plains and in many of them it is one of the most important and valuable forest trees. In the Southwest, western yellow pine is by far the most important timber tree, constituting over 80 per cent of the commercial forests of Arizona and New Mexico, approximately 30 billion board feet.

During the past 12 years studies have been in progress to determine the effect of the mistletoe (*Razoumofskya cryptopoda* (Engelm.) Cov.) on the growth and seed production of western yellow pine. This parasite is the most widely distributed and one of the most

Note.—The author's names are in alphabetical order. The writers are indebted to Silviculturist G. A. Pearson, of the Fort Valley Experiment Station, for the permanent sample-plot data contained in Tables 11 and 17, for the data on the 1915 seed collection contained in Table 18, and for his general interest in the investigation.

serious enemies of the western yellow pine, and it has confronted the forester from the beginning of silvicultural practice in the Southwest. Especially on southern exposures and near the lower limit of the type, areas may be found on which fully 75 to 90 per cent of all the trees above 6 inches in diameter are infected with mistletoe.

In marking western yellow pine, there is often a question as to the advisability of cutting trees of various ages and degrees of mistletoe infection, or of allowing them to remain as seed trees and form a part of the future stand which will provide the basis for a subsequent cut. This problem involves not only a study of the effect of mistletoe on the rate of growth and the longevity of its host, but also of the effect of the parasitism on the amount and periodicity of seed production.

PHYSICAL AND CLIMATIC FEATURES OF THE REGION.

The areas in which the intensive studies were conducted lie within the Coconino and Tusayan National Forests on the Colorado Plateau, near the San Francisco Mountains in northern Arizona. The general topography of the plateau is rolling and consists of alternating flats comparatively free from rock and of rather low ridges which are very rocky. The underlying rock of the plateau consists principally of Coconino sandstone and Kaibab limestone overlaid by a lava flow of basalt and acidic volcanic rocks, mainly dacite, andesite, rhyolite, and latite, which constitute the main outcrops and surface rocks of the region. The soil varies widely from a fine sandy loam to a reddish friable clay, often containing an admixture of gravel and large volcanic bowlders. In the greater part of the region northeast of the San Francisco Mountains the soil is covered with black volcanic cinders to depths varying from one-half inch to about 18 inches. Mistletoe infection is rare on these cinder areas and where found at all is light. The level mesas and lower slopes of the plateau, ranging from approximately 6,500 to 8,500 feet in elevation, are covered with a forest, of which approximately 95 per cent is western yellow pine, constituting the most extensive forest of this species in North America.

The climate of that portion of the Colorado Plateau which is covered with a western yellow pine forest is indicated by the climatological data which have been secured at the Fort Valley Forest Experiment Station. Pearson's [1] studies in this locality, together with the records of the United States Weather Bureau throughout the region, have shown that the climate is characterized by marked seasonal variations in precipitation, atmospheric humidity, and

[1] Pearson, G. A. A Meteorological Study of Parks and Timbered Areas in the Western Yellow Pine Forests of Arizona and New Mexico. Monthly Weather Review, vol. 41: 1615–1629, 1914.

wind movement, and great daily ranges of atmospheric temperature. The amount of sunshine is unusually high. The mean annual precipitation in the western yellow pine forest amounts to between 20 and 25 inches, which occurs in two well-defined periods during July and August in the form of thundershowers and from November to April in the form of snow. The period from about April 15 to July 15 is characterized by desiccating southwest winds and excessive evaporation, which, together with the small amount of precipitation, produce conditions adverse to most types of vegetation. The high rate of evaporation, low atmospheric humidity, and high wind velocity very often cause excessive transpiration from plants. The climatic and soil conditions are such that nowhere within the western yellow pine type of the Southwest does this species make rapid growth.

The influence of such climatological conditions is generally considered unfavorable to the best development of the host and favorable to the distribution and growth of the parasitic mistletoe. Weir [2] has emphasized the fact that the ecological relationships of the mistletoes, although they are parasitic, are similar to those of other cholorphyllaceous plants in that they also respond to light, gravity, and certain chemical stimuli, while the marked variations in temperature to which the host readily responds are only slightly effective on the parasite. The low atmospheric humidity has a very slight influence on the xerophytic mistletoe, while the great amount of sunshine is favorable to the parasite. The unusually high winds of the Southwest frequently cause rather serious losses to western yellow pine stands in exposed situations through windfall, and the wind is known to aid in the dissemination of the mistletoe seed from tree to tree.

It follows that, where a virulent parasite responds favorably to its habitat, the host will rapidly deteriorate on the more unfavorable sites. From numerous observations made in various parts of the Southwest, it is apparent that a rather definite relation exists between the unfavorableness of the site and the degree of mistletoe infection. The percentage of infection and the resulting mortality of the host is usually higher on exposed dry ridges and south slopes than on the more favorable sites. This condition is very apparent on the Santa Fe National Forest in northern New Mexico.

THE WESTERN YELLOW PINE MISTLETOE.

The family Loranthaceæ has two genera in the United States, Phoradendron and Razoumofskya. The species of Phoradendron are parasitic on both hardwoods and conifers, but mainly on hard-

[2] Weir, James R. The Larch Mistletoe: Some Economic Considerations of Its Injurious Effects. U. S. Dept. of Agri. Bul. 317, pp. 5–10, 1916.

woods, while the genus Razoumofskya is found exclusively on conifers. Several species of the latter genus are rather common in the western United States and in some localities have become very serious parasites. *Razoumofskya cryptopoda,* the western yellow pine mistletoe, is one of the most widely distributed of all the species, usually being found wherever the western yellow pine grows. (Pl. I, Fig. 1.)

Razoumofskya cryptopoda flowers in Arizona and New Mexico during April and May, and the fruit matures in August and September of the next year. When the seeds begin to ripen, the berries gradually turn downward on their pedicels until the base of each berry when fully mature points upward. The gelatinous seeds when ripe are suddenly and forcibly ejected upward to a distance of several yards by the giving way of a ring of tissue situated near the base of the berry. This method of seed dissemination is common to all species of Razoumofskya. Experiments and extended observations indicate that the aerial portions of both staminate and pistillate plants die and fall from the trees after one season of flowering and fruiting. (Pl. I, Fig. 2.)

EFFECT OF MISTLETOE ON GROWTH OF HOST.

The study of the effect of mistletoe on its host was accomplished (1) by periodic measurements and observations of standing trees, both infected and healthy; and (2) by detailed growth studies and observations of infected and healthy felled trees.

EFFECT ON BOLE OF TREE.

Ninety-one healthy and mistletoe-infected trees between 10 and 30 inches in diameter breast high on three different areas within a radius of 5 miles of the Fort Valley Experiment Station were tagged, numbered, measured, and mapped in 1910 with the object of determining the effect of mistletoe on the diameter and height-growth of the host, the diameter growth of limbs, and the growth of the merchantable contents of the bole. The diameters were measured with a diameter tape at 1, 4.5, 17, and 33 feet above the ground. The total heights were measured with a Forest Service standard hypsometer. The diameters of 20 healthy and 34 mistletoe-infected limbs falling in different infection classes were measured on 18 standing trees with a view of determining the effect of mistletoe on the growth of limbs. The points of measurement at 6 inches from the bole of the tree and every 6 inches beyond this point were marked by driving a 6-penny copper nail into the wood. All of the trees were remeasured in 1915 and were reclassified into four degrees of mistletoe infection, according to the prevalence of mistletoe on the tree, as follows: O, healthy trees without mistletoe; X, light

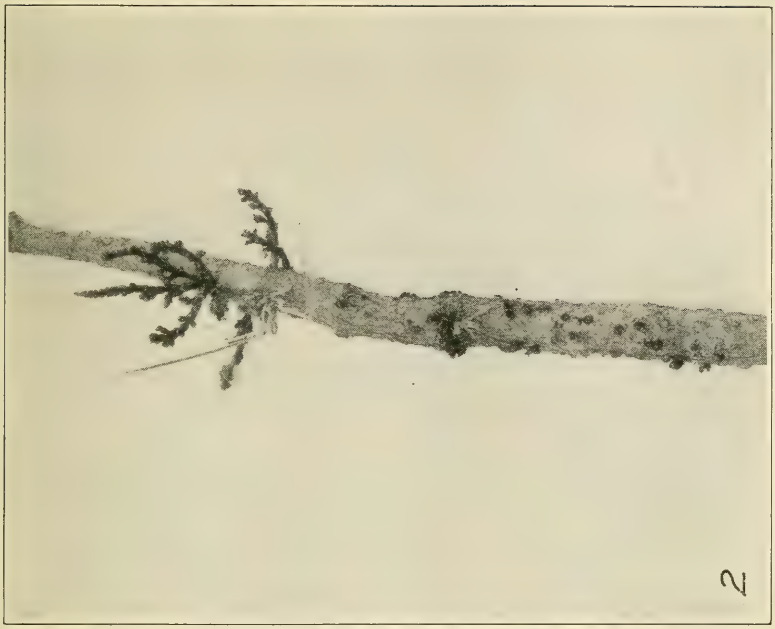


FIG. 2.—Advance of a mistletoe lesion on a twig of western yellow pine; dead stems of early infection in the center and young, vigorous mistletoe plants at the upper edge of the lesion.

FIG. 1.—A typical mistletoe colony on western yellow pine. The stems of dead and dying mistletoe plants are in the center and the youngest plants are seen at each end of the lesion.

mistletoe infection; XX, medium mistletoe infection; XXX, heavy mistletoe infection.

In order to check any material effect that the different crown classes might have on the rate of growth the trees were also classified, according to their dominance or relative position in the crown canopy of the group, into the following crown classes:

Isolated.—Trees growing in the open which do not form a contiguous part of the regular group canopy.

Dominant.—Trees with crowns extending above the general level of the group canopy and receiving full light from above and partly from the side; larger than the average trees in the group, and with crowns well developed but possibly somewhat crowded.

Codominant.—Trees with crowns forming the general level of the group canopy and receiving full light from above, but comparatively little from the sides; usually with medium-sized crowns more or less crowded on the sides.

Intermediate.—Trees with crowns below, but still extending into the general level of the group canopy, receiving a little direct light from above but none from the sides, usually with small crowns considerably crowded on the sides.

Suppressed.—Trees with crowns below the general level of the group canopy and receiving no direct light either from above or from the sides; usually with small, poorly developed crowns.

There are two well-recognized forms of *Pinus ponderosa*, "black jack" and "yellow pine," based on age, rate of growth, and the resulting color of the bark. The term "black jack" applies to the young, vigorous trees under 125 to 150 years old which are characterized by a dark, almost black, or dark brown, narrow-furrowed bark. The "yellow pine" form comprises the older trees, which are characterized by a yellowish or reddish brown, widely furrowed bark. There is a marked difference in the form and volume of black jacks and yellow pines. The average black jack has a greater taper, a more rapid rate of growth, and approximately 10 per cent smaller cubic volume than the average yellow pine of the same diameter and height, which were the chief reasons for the segregation of black jacks and yellow pines.

The mean diameter growth or accretion of the standing black jacks for the 5-year period from 1910 to 1915, grouped according to degree of mistletoe infection, is shown in Table 1. The diameters were averaged by infection classes for each year mentioned, and the difference was computed as the growth during the 5-year period or the periodic accretion. The average growth per year during the period considered is termed the periodic annual accretion. The data show an almost consistent decrease in the diameter growth of black jack with the degree of mistletoe infection. The slight inconsistency exhibited in the rate of diameter growth of the *o* and *x* infection

classes might be explained by the fact that of the 27 trees in the infection class, 11 per cent were isolated trees which did not form a part of the forest canopy, 28 per cent were dominant, 57 per cent were codominant, and 4 per cent were intermediate trees, while with the *x* infection class 60 per cent were isolated trees which did not form a part of the forest canopy and 40 per cent were in the codominant crown class. Table 2 consistently shows a decrease in the rate of diameter growth of yellow pine which varies directly with the degree of mistletoe infection.

TABLE 1.—*Comparison of the average diameter growth or accretion of 58 standing black jacks, for a 5-year period, grouped according to degree of mistletoe infection.*

Degree of infection.	Diameter breast-high.		Accretion, 1910–1915.		Basis.
	1910	1915	Periodic.	Periodic Annual.	
	Inches.	*Inches.*	*Inches.*	*Inch.*	*Trees.*
o	16.16	16.97	0.81	0.16	27
x	17.65	18.63	.98	.20	6
xx	15.82	16.57	.75	.15	15
xxx	14.24	14.36	.12	.02	10

TABLE 2.—*Comparison of the average diameter growth or accretion of 33 standing yellow pines, for a 5-year period, grouped according to degree of mistletoe infection.*

Degree of infection.	Diameter breast-high.		Accretion, 1910–1915.		Basis.
	1910	1915	Periodic.	Periodic annual.	
	Inches.	*Inches.*	*Inch.*	*Inch.*	*Trees.*
o	24.60	25.30	0.70	0.14	9
x	25.56	26.04	.48	.10	8
xx	22.14	22.44	.30	.06	7
xxx	21.49	21.61	.12	.02	[1] 9

[1] Five trees of this class died during the 5-year period and were not included in the computation.

TABLE 3.—*Comparison of total volume growth or increment of 58 standing black jacks, for a 5-year period, grouped according to degree of mistletoe infection.*

Degree of infection.	Total volume.		Increment, 1910–1915.			Basis.
	1910	1915	Periodic.	Periodic annual.		
	Cubic feet.	*Cubic feet.*	*Cubic feet.*	*Cubic feet.*	*Per cent.*	*Trees.*
o	987.2	1,100.9	113.7	22.7	2.30	27
x	291.4	324.4	33.0	6.6	2.26	6
xx	434.0	470.6	36.6	7.3	1.68	15
xxx	234.9	243.2	8.3	1.7	.72	10

TABLE 4.—*Comparison of the total volume growth or increment of 33 standing yellow pines, for a 5-year period, grouped according to degree of mistletoe infection.*

Degree of infection.	Total volume.		Increment, 1910–1915.			Basis.
	1910	1915	Periodic.	Periodic annual.		
	Cubic feet.	*Cubic feet.*	*Cubic feet.*	*Cubic feet.*	*Per cent.*	*Trees.*
o	1,151.0	1,226.0	75.0	15.0	1.30	9
x	1,206.0	1,250.0	44.0	8.8	.73	8
xx	706.0	725.0	19.0	3.8	.54	7
xxx	801.0	809.0	8.0	1.6	.20	[1] 9

[1] Five trees of this class died during the 5-year period and were not included in the computation.

Table 3 shows the total volume growth or increment of the standing black jacks for the same 5-year period, grouped by infection classes. The total volumes were computed by applying a volume table based on diameter and total height to the dimensions of each tree as measured in 1910 and 1915. It was found from taper measurements that volume tables could safely be applied to the individual trees. The volumes of all trees were totaled by infection classes. The difference between the total volumes at each time of measurement represents the periodic increment, and the average volume growth per year during the period considered is the periodic annual increment. Table 4 shows the increment of the standing yellow pines for the same 5-year period. Both forms of western yellow pine exhibit a consistent decrease in the increment of those trees which are infected with mistletoe varying directly with the degree of infection.

Bole measurements were made at 16-foot intervals to insure greater accuracy in the study of the effect of mistletoe on the growth of the merchantable contents of the bole of the tree. Table 5 gives a comparison of the diameter growth of the bole of 33 trees at 4.5, 17, and 33 feet above the ground. The comparative increments of the same trees are shown in Table 6. The apparent discrepancy between the rate of growth of the uninfected and lightly infected classes, as was noted above, is apparently due either to the varying proportions of the trees among the different crown classes or it may be possible that the infection at first results in a slight stimulation of the tree. In computing the volume, each section below the highest point of measurement was cubed as a cylinder by averaging the basal areas of the ends and multiplying by the length of the section;[3] that portion above was considered as the top of the tree and its volume was computed as that of a cone.

The growth of the standing trees was further checked by complete stem analysis of 102 felled trees. Sections were examined as near to the surface of the ground as possible, at 4.5 feet above the ground,

[3] This is known as the Smalian method. See Graves, Henry S., Forest Mensuration, pp. 91–93, New York, 1907.

and at every 8 feet above this point. The measurements were recorded by 5-year periods instead of by decades, as is the usual practice in complete stem analysis. The trees were selected as nearly as possible from the same site, kind of stand, and the same age and crown classes. Only those trees free from abnormalities or other possible causes of deterioration or conditions deterrent to their growth were studied, thus permitting only two variables to enter into the results, the age of the tree and the degree of mistletoe infection. The classification of the tree according to degree of infection represents the consensus of opinion of three different observers.

The basic data for each of the individual felled trees which were analyzed to show the effect of mistletoe on the growth and seed production of western yellow pine have been arranged in Table 7, according to the age of the trees. In compiling the stem analyses the data for each tree were computed separately. The diameters and heights of each tree for each fifth year, dating back from the year of analysis, were correlated with age in growth-analysis diagrams, from which the dimensions of each tree for each integral 5 years of age or quinquennium were read.

TABLE 5.—*Comparison of the average diameter growth or accretion of 33 standing black jacks, for a 5-year period, at 4.5, 17, and 33 feet from ground, grouped according to degree of mistletoe infection.*

Degree of infection.	Diameter outside bark.						Accretion, 1911–1916.						Basis.
	1911			1916			Periodic.			Periodic annual.			
	4.5 feet.	17 feet.	33 feet.	4.5 feet.	17 feet.	33 feet.	4.5 feet.	17 feet.	33 feet.	4.5 feet.	17 feet.	33 feet.	
	In.	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*Trees.*
o	17.93	15.28	12.69	19.03	16.30	13.71	1.10	1.02	1.02	0.22	0.20	0.20	16
x	22.25	19.59	14.14	23.40	20.85	15.25	1.15	1.26	1.11	.23	.25	.22	4
xx	15.92	13.20	8.65	16.78	13.81	9.46	.86	.61	.81	.17	.12	.16	7
xxx	16.47	14.42	9.19	17.15	14.64	9.31	.68	.22	.12	.14	.04	.02	6

TABLE 6.—*Comparison of the total volume growth or increment of 33 standing black jacks, for a 5-year period, grouped according to degree of mistletoe infection.*

Degree of infection.	Total volume.		Increment, 1911–1916.			Basis.
	1911	1916	Periodic.	Periodic annual.		
	Cubic feet.	*Cubic feet.*	*Cubic feet.*	*Cubic feet.*	*Per cent.*	*Trees.*
o	919.76	1,047.40	127.64	25.53	2.78	16
x	359.07	410.65	51.58	10.32	2.87	4
xx	286.83	316.08	29.25	5.85	2.04	7
xxx	262.65	273.97	11.32	2.26	.86	6

TABLE 7.—*Basic data for 107 felled trees showing the effect of mistletoe on the growth and seed production of western yellow pine.*

Tree number.	Age.	Diameter breast high.	Diameter growth for last 5 years.	Total height.	Height growth for last 5 years.	Total volume.	Volume growth for last 5 years.	Degree of infection.[1]	Crown class.[2]	Average length of leaves.	Average length of leaf tufts.	Seed crop, 1915.[3]
	Years.	*Inch.*	*Inch.*	*Feet.*	*Feet.*	*Cu. ft.*	*Cu. ft.*			*Inch.*	*Inch.*	
58	23	4.0	1.5	15.5	4.5	1.81	0.39	o	X	5.5	19.3	O
75	23	4.6	1.6	14.5	3.0	.84	.55	x	C	4.1	7.0	O
59	24	2.8	.7	13.5	3.5	.27	.08	o	C	5.6	19.3	O
74	24	3.2	1.0	13.5	3.5	.36	.17	o	C	5.1	11.6	O
67	25	1.9	.4	9.0	1.0	.11	.03	xx	C	2.6	5.0	O
62	26	2.4	.6	13.5	3.0	.22	.11	o	C	4.0	9.6	O
70	26	2.0	1.0	11.5	3.5	.12	.06	o	D	5.1	8.0	O
85	27	.....	.....	3.1	.5	.01	.001	xxx	X	3.0	3.2	O
72	28	2.4	1.2	11.5	4.0	.19	.09	o	D	6.0	10.3	O
73	28	6.2	1.8	24.5	4.5	2.02	.99	o	C	5.8	11.3	O
86	28	.....	.....	3.2	.8	.021	.014	xxx	X	3.6	5.3	O
84	29	.....	.....	2.8	.3	.009	.001	xxx	X	2.8	3.4	O
60	30	5.4	.6	23.5	3.0	1.58	.47	x	D	4.1	10.0	O
69	30	1.9	.4	9.5	2.0	.09	.01	x	I	3.3	4.3	O
71	30	5.4	1.6	17.5	4.0	.88	.32	o	C	5.6	11.3	O
22	30	4.8	1.8	17.5	4.5	.98	.53	o	D	5.6	23.3	O
65	31	4.6	1.0	17.5	3.0	.80	.29	x	C	4.1	8.6	O
15	31	.....	.....	3.5	1.0	.07	.06	x	X	3.8	9.3	O
68	32	3.5	.2	10.5	1.0	.41	.13	xx	X	2.1	3.3	O
17	33	.....	.....	3.0	.5	.01	.002	xx	X	.....	.....	O
61	33	4.8	.5	16.0	1.5	1.06	.27	xxx	C	2.7	5.5	O
64	33	3.0	.5	13.5	2.0	.33	.13	xx	I	3.3	10.3	O
63	35	.5	.2	5.5	.5	.09	.02	xxx	I	2.3	3.0	O
66	35	4.0	1.2	17.5	3.5	1.03	.42	x	C	4.1	8.6	O
83	37	.....	.....	4.3	.7	.014	.002	xxx	X	3.1	2.8	O
107	37	7.1	.....	21.0	.....	2.40	.....	o	D	5.2	8.5	O
18	39	5.1	1.1	18.0	3.0	1.78	.69	o	X	5.3	13.0	O
20	46	6.2	1.1	17.5	2.0	1.85	.63	xx	X	3.7	4.7	O
19	53	6.2	.8	27.0	3.0	3.11	1.03	x	X	5.6	17.0	O
29	60	15.6	1.5	47.5	3.5	21.24	5.05	o	X	6.8	13.3	O
47	65	13.2	1.6	51.5	5.0	19.79	4.69	o	C	5.3	8.0	L
81	65	10.8	1.3	46.0	4.5	11.22	3.38	o	C	5.8	22.3	O
82	65	9.0	.4	33.0	1.5	5.09	.76	xxx	C	4.1	6.6	O
52	66	11.2	.4	30.5	.5	8.14	.99	xx	X	3.5	5.0	O
89	66	7.9	.7	33.5	2.5	3.35	.72	x	X	4.6	7.7	O
48	69	10.8	1.1	39.0	2.5	9.09	2.11	xx	C	4.5	6.0	O
57	70	15.8	2.0	60.0	5.0	27.38	6.12	o	C	6.3	7.3	L
80	70	8.8	1.0	37.5	1.5	5.63	.94	o	S	6.6	7.5	O
88	71	7.5	.6	34.5	1.5	4.29	.47	x	C	4.3	6.7	O
8	72	4.4	.3	17.0	1.0	.85	.11	xx	I	5.6	.....	O
46	72	15.6	1.1	43.5	3.0	19.84	3.59	o	X	5.1	10.6	O
37	74	7.0	.1	20.0	1.0	1.66	.08	xxx	X	3.5	3.1	O
21	75	7.4	.4	30.0	.5	3.77	.49	xxx	X	2.6	2.5	O
98	76	19.5	1.5	60.5	3.5	40.70	4.79	o	C	5.0	6.7	O
10	78	11.8	.4	36.5	.5	10.17	.67	xx	X	4.5	.....	.....
77	78	11.7	.5	38.5	.5	10.68	1.08	xxx	X	3.6	5.3	O
49	79	9.5	.3	32.5	1.0	5.47	.53	xxx	C	4.0	4.6	O
78	79	5.4	.4	26.0	1.0	2.08	.43	xx	S	3.5	4.3	O
104	79	14.5	.....	42.0	.....	19.00	.....	o	X	3.8	6.2	L
1	80	12.6	.2	39.5	.7	14.60	1.13	xxx	X	.....	.....	O
11	80	10.8	1.5	34.5	3.5	7.82	2.21	o	X	6.3	18.0	O
103	80	7.5	.....	20.0	.....	2.50	.....	xxx	X	2.8	4.2	O
5	82	8.0	.4	33.5	.5	5.91	.33	xxx	C	.....	.....	O
9	82	10.6	.2	44.5	.5	9.64	.43	xx	X	3.3	.....	O
44	82	11.2	.6	39.0	2.5	9.07	1.56	x	C	4.3	5.0	O
90	82	6.9	.3	28.5	.5	2.46	.36	x	C	4.3	5.3	O
6	83	10.8	1.5	47.5	4.0	10.67	2.76	o	D	5.8	.....	O
38	83	9.8	.2	37.5	.2	7.65	.30	xxx	X	3.3	5.0	O
105	83	8.1	.....	26.0	.....	3.55	.....	xxx	C	3.5	4.2	O
106	83	15.2	.....	49.0	.....	22.50	.....	o	C	5.5	6.1	L
54	84	7.1	.5	27.5	2.0	2.51	.37	xxx	C	4.3	4.6	O
43	85	8.2	.3	40.5	2.5	6.65	1.23	xx	C	4.1	5.0	O
51	85	14.4	1.2	47.5	3.0	21.19	3.62	o	C	5.6	8.0	O
24	87	11.1	1.6	41.5	4.0	10.93	2.84	o	X	6.0	22.0	O
79	88	5.8	.4	24.5	.5	1.87	.23	xxx	S	4.1	5.6	O
14	89	10.4	.5	35.5	2.0	7.84	.98	xxx	D	3.6	5.7	.....
53	92	14.0	1.1	46.5	2.5	16.00	2.69	o	C	5.6	8.6	L
13	93	7.8	.2	32.5	.5	4.26	.27	xx	X	5.1	7.8	O

[1] Degree of infection classified as follows: o = healthy trees without mistletoe, x = light mistletoe infection, xx = medium mistletoe infection, xxx = heavy mistletoe infection.
[2] Crown class of trees classified as follows: X = isolated, D = dominant, C = codominant, I = intermediate, S = suppressed.
[3] Seed crop classified as follows: H = heavy, G = good, M = medium, L = light, O = none.

TABLE 7.—*Basic data for 107 felled trees showing the effect of mistletoe on the growth and seed production of western yellow pine*—Continued.

Tree number.	Age.	Diameter breast high.	Diameter growth for last 5 years.	Total height.	Height growth for last 5 years.	Total volume.	Volume growth for last 5 years.	Degree of infection.	Crown class.	Average length of leaves.	Average length of leaf tufts.	Seed crop, 1915.
	Years.	*Inch.*	*Inch.*	*Feet.*	*Feet.*	*Cu. ft.*	*Cu. ft.*			*Inch.*	*Inch.*	
23	93	6.8	0.1	22.5	1.0	2.30	1.80	xxx	C	3.1	3.3	O
91	93	8.9	.4	36.0	1.0	5.65	1.01	x	X	4.5	6.5	O
2	94	12.0	1.5	40.5	1.0	15.18	4.40	o	X	.....	.....	O
42	94	14.8	.2	41.5	.5	20.03	.67	xxx	X	4.5	5.6	O
76	94	9.8	.7	39.0	1.0	7.80	.77	xxx	C	3.1	4.6	O
7	95	4.0	.1	21.0	1.0	.84	.16	xxx	S	4.1	.....	O
56	95	14.4	.3	42.5	1.0	16.37	.42	xxx	C	4.0	5.0	O
87	97	9.0	.5	43.0	1.0	7.06	.85	x	C	4.6	5.3	O
28	98	18.1	1.5	64.5	6.0	47.49	6.48	x	X	6.3	11.3	O
25	100	8.3	.2	30.0	.5	4.23	.28	xxx	D	4.5	3.6	O
55	100	14.6	.2	49.5	1.0	20.05	1.08	xxx	C	5.2	5.5	O
99	102	20.6	1.0	64.5	3.0	52.44	6.81	o	C	4.7	6.3	O
12	104	12.4	.5	41.5	1.5	13.13	1.17	o	X	5.3	6.1	O
93	104	21.6	1.1	73.0	3.5	63.47	5.73	o	C	4.8	5.7	L
95	105	20.4	.6	60.5	1.5	62.11	4.30	x	C	5.2	7.2	O
40	106	9.4	.8	53.0	3.0	8.62	.92	xx	C	5.3	6.6	O
39	112	11.6	1.2	62.0	3.5	18.82	5.59	o	C	5.0	10.6	O
96	114	18.8	.6	70.5	1.0	43.68	1.64	xx	C	4.3	6.8	O
94	117	20.4	1.0	78.0	3.0	69.85	5.05	o	C	5.1	6.2	L
45	120	19.4	.4	67.0	1.0	42.59	1.32	xx	C	4.3	3.6	O
97	120	22.4	1.7	79.5	2.5	83.56	11.32	o	C	5.4	6.8	L
41	121	11.9	.8	58.0	1.0	16.10	1.09	xxx	C	5.3	6.6	O
27	123	17.6	.1	46.5	.5	21.86	.58	xxx	X	4.6	5.1	O
4	124	20.2	1.7	68.5	1.0	67.68	9.40	o	X	6.0	9.0	O
92	125	17.1	.4	68.0	1.0	43.33	3.75	xx	C	5.1	5.0	O
3	126	20.3	.3	55.5	.3	42.03	1.49	xxx	X	4.0	2.5	O
50	130	23.4	2.3	79.5	1.5	92.78	8.56	o	D	5.0	8.3	M
26	134	18.2	.2	45.0	.5	25.23	.82	xxx	D	3.6	2.5	O
16	138	20.2	.4	59.5	.5	50.01	3.74	x	X	5.1	11.5	O
36	214	19.2	1.2	67.5	1.5	44.90	4.27	o	C	5.6	7.1	L
102	214	23.0	1.4	85.0	1.0	108.80	7.98	o	D	5.5	5.3	M
33	217	15.2	.5	58.5	1.0	32.92	2.62	xxx	X	4.7	8.3	L
30	218	18.2	.4	78.5	.2	59.68	2.55	xxx	C	3.5	.....	O
100	218	20.8	.5	77.5	1.5	71.92	2.63	o	C	5.3	5.2	O
101	218	25.6	1.3	87.5	1.0	133.67	10.17	o	X	4.8	5.8	L
31	220	16.0	.1	84.5	.3	54.91	1.15	xxx	C	5.0	7.1	O
32	220	21.6	.8	87.5	1.0	90.26	7.06	o	D	5.8	7.3	M
34	230	25.6	.4	76.5	.3	107.47	2.88	xxx	X	5.2	8.8	O
35	233	17.6	.2	72.0	.5	65.10	5.68	xxx	C	4.5	5.6	O

Figure 1 shows the graphic growth analysis diagram for tree No. 4, a typical healthy western yellow pine, while Figure 2 shows the same kind of a diagram for tree No. 27, which was heavily infected with mistletoe. Both trees grew within a short distance of each other on the same site; they were of practically the same age and both belonged to the isolated crown class and the 101 to 140 year age class; therefore these factors can not be held accountable for the material falling off in the increment of the heavily infected tree. The very marked decrease in the rate of growth during the last 30 years, evidently due to the parasitism of the mistletoe, is very clearly shown by the closeness of the last seven quinquennial lines near the outside of the cone in Figure 2, which represents the growth of tree No. 27.

A set of curves was drawn for each tree showing the relation of age to diameter breast high, total height, and volume. This curving eliminated the irregularities and irrelevant abnormalities occurring in each tree. The data for the individual trees were then averaged by a series of harmonized curves for each infection and 40-year age

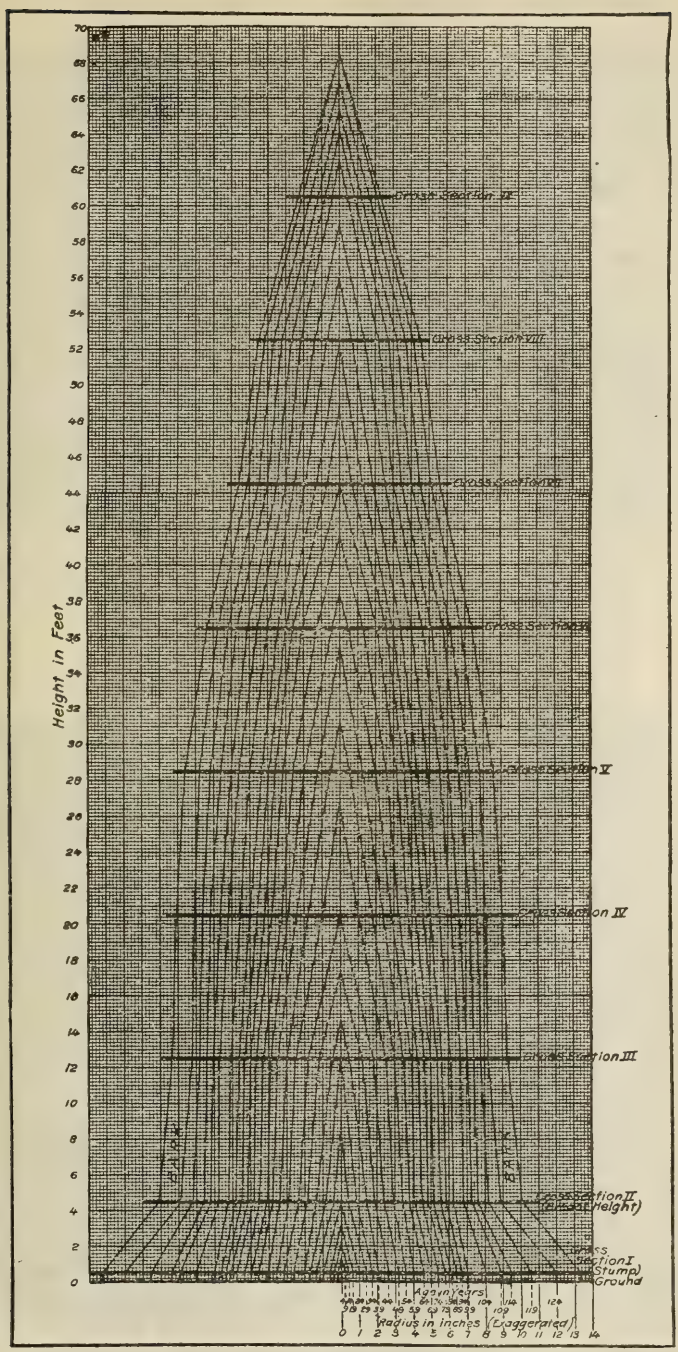


FIG. 1.—Graphic representation of the growth analysis of felled tree No. 4, a sound healthy western yellow pine. (Height greatly reduced in porportion to diameter.)

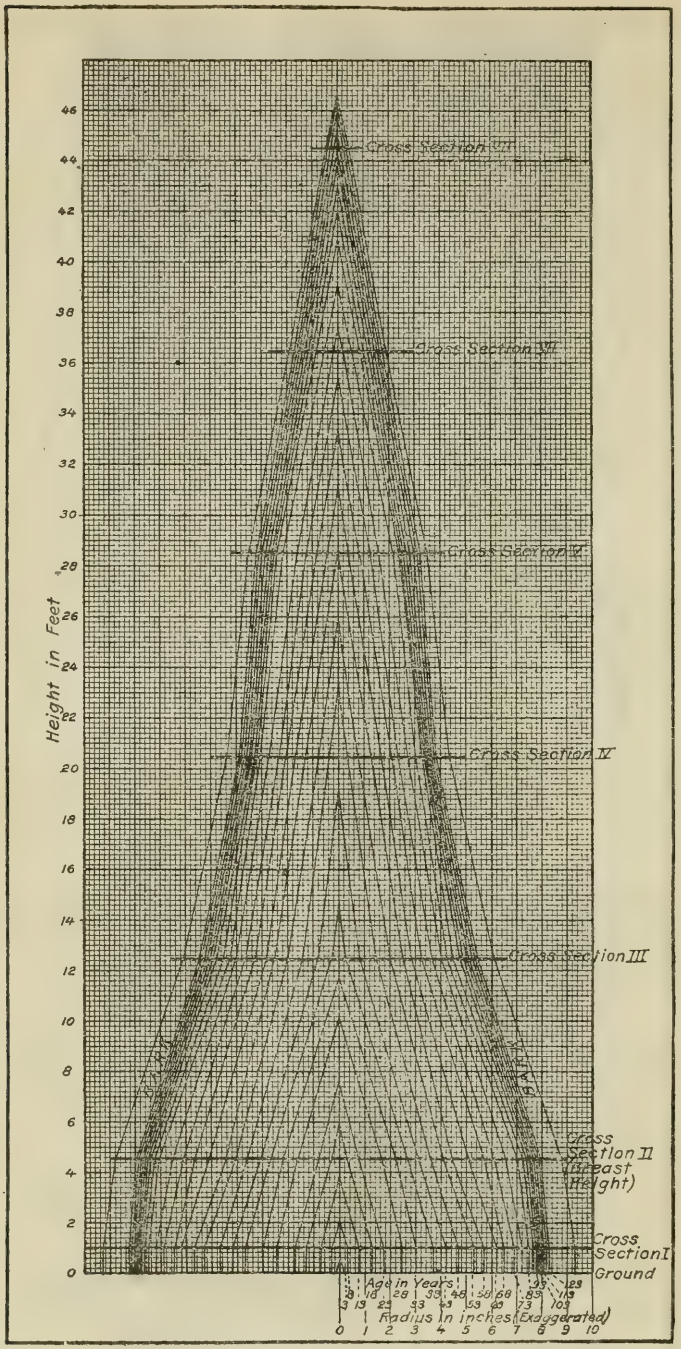


FIG. 2.—Graphic representation of the growth analysis of felled tree No. 27, a western yellow pine heavily infected with mistletoe. (Height greatly reduced in proportion to diameter.)

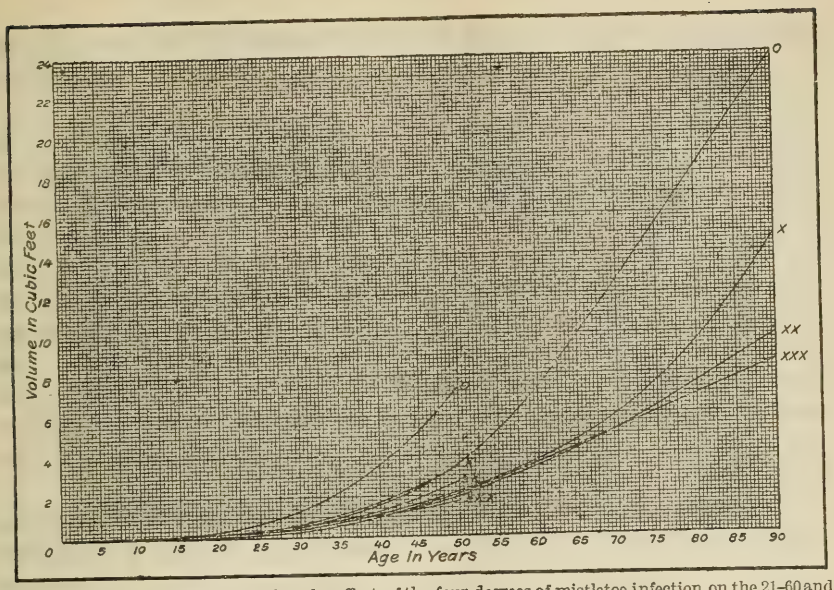


FIG. 3.—Volume-age curves showing the effect of the four degrees of mistletoe infection on the 21–60 and 61–100 year age classes.

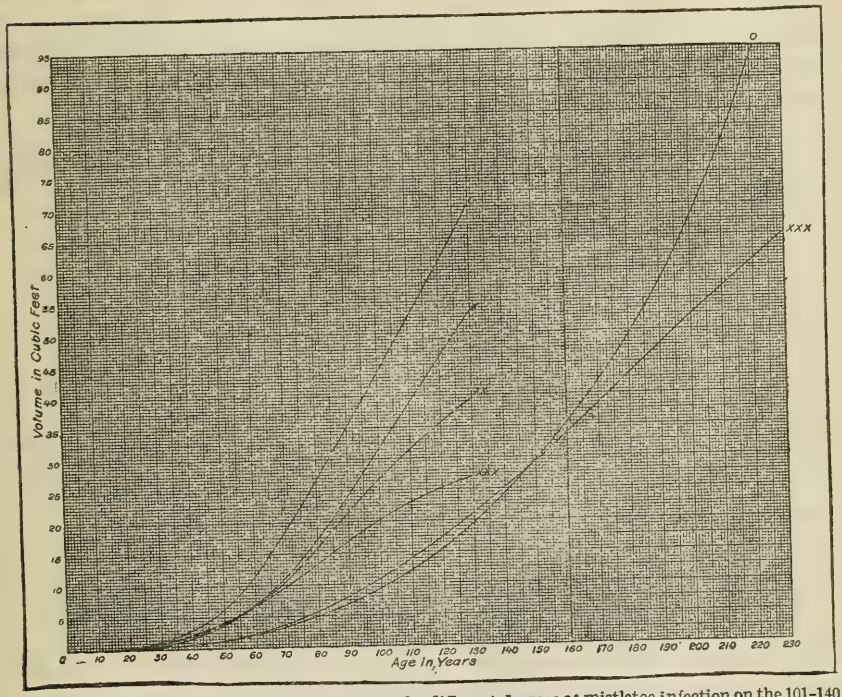


FIG. 4.—Volume-age curves showing the effect of the different degrees of mistletoe infection on the 101–140 and the 201–240 year age classes.

class. Forty-year age classes were used instead of the usual 20-year age classes, because they provided a greater number of trees as the basis for each age and infection class.

The harmonized volume-age curves for the 21 to 60 and the 61 to 100 year age classes are shown in Figure 3, which indicates that the mistletoe infection was sufficiently severe to retard the rate of growth of the more heavily infected trees of these two age classes by approximately 20 years. Figure 4 shows a similar retardation of the increment for the 101 to 140 and the 201 to 240 year age classes, except that the rate of growth of the more heavily infected trees of these age classes has been on the decline for the past 70 to 80 years. The curves in both figures show conclusively that the current increment is directly dependent upon the degree of mistletoe infection. Generally speaking, the degree of mistletoe infection increases with the length of time which a tree has been infected.

A further comparison of the average diameter growth or accretion of the felled western yellow pine trees for the 25-year period from 1890 to 1915, grouped by 40-year age classes and degree of mistletoe infection, is shown in Table 8. A similar comparison of the average height growth or accretion of the same trees is given in Table 9. Table 10 shows a comparison of the average volume growth or increment of the same trees for the same period, similarly grouped by age and infection classes. The 21 to 60, 61 to 100, and the 101 to 140 year age classes in Tables 8, 9, and 10 are composed entirely of black jacks, while yellow pines constitute the 201 to 240 year age class.

TABLE 8.—*Comparison of the average diameter growth or accretion of 102 felled western yellow pine trees, for a 25-year period, grouped by age classes and degree of mistletoe infection.*

Age class.	Degree of infection.	Diameter breast high.		Accretion, 1890–1895, periodic annual.	Diameter breast high, 1900.	Accretion, 1895–1900, periodic annual.	Diameter breast high, 1905.	Accretion, 1900–1905, periodic annual.	Diameter breast high, 1910.	Accretion, 1905–1910, periodic annual.	Diameter breast high, 1915.	Accretion, 1910–1915, periodic annual.	Basis.
		1890	1895										
Years.		*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*Trees.*
21 to 60	o	0.8	1.0	0.04	1.6	0.12	2.3	0.14	3.7	0.28	5.0	0.26	11
	x	.2	.6	.08	1.4	.16	2.5	.22	3.5	.20	4.4	.18	6
	xx	.1	.4	.06	.8	.08	1.3	.10	1.8	.10	2.1	.06	7
	xxx	.....	.3	.06	.6	.06	.7	.02	.9	.04	1.1	.04	5
61 to 100	o	7.2	8.2	.20	9.3	.22	10.4	.22	11.5	.22	13.0	.30	12
	x	6.6	7.3	.14	8.0	.14	8.7	.14	9.3	.12	9.9	.12	7
	xx	6.0	6.8	.16	7.5	.14	8.1	.12	8.6	.10	9.0	.08	9
	xxx	6.8	7.5	.14	8.2	.14	8.7	.10	9.2	.10	9.4	.04	17
101 to 140	o	15.0	15.7	.14	16.5	.16	17.5	.20	18.6	.22	19.8	.24	6
	x	14.5	15.1	.12	15.9	.16	16.7	.16	17.5	.16	18.3	.16	4
	xx	14.8	15.2	.08	15.7	.10	16.1	.08	16.5	.08	16.9	.08	6
	xxx	15.2	15.6	.08	15.9	.06	16.3	.08	16.7	.08	17.0	.06	4
201 to 240	o	17.8	18.5	.14	19.3	.16	20.1	.16	21.1	.20	22.1	.20	5
	xxx	16.7	17.0	.06	17.4	.08	17.7	.06	17.9	.04	18.2	.06	5

TABLE 9.—*Comparison of the average height growth or accretion of 102 felled western yellow pine trees, for a 25-year period, grouped by age classes and degree of mistletoe infection.*

Age class.	Degree of infection.	Total height.		Accretion 1890–1895, periodic annual	Total height, 1900.	Accretion 1895–1900, periodic annual	Total height, 1905.	Accretion 1900–1905, periodic annual	Total height, 1910.	Accretion 1905–1910, periodic annual	Total height, 1915.	Accretion 1910–1915, periodic annual	Basis.
		1890	1895										
Years.		*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Trees.*
21 to 60	o	3.2	5.4	0.44	8.0	0.52	11.3	0.66	14.9	0.72	18.6	0.74	11
	x	2.6	5.1	.50	8.3	.64	12.2	.78	15.3	.62	18.2	.58	6
	xx	1.6	3.2	.32	4.6	.28	6.1	.30	7.4	.26	8.6	.24	7
	xxx	1.3	2.5	.24	3.8	.26	4.9	.22	5.7	.16	6.3	.12	5
61 to 100	o	27.4	31.5	.82	35.6	.82	39.5	.78	43.2	.74	46.6	.68	12
	x	29.6	32.2	.52	34.6	.48	36.8	.44	38.8	.40	40.8	.40	7
	xx	23.7	26.1	.48	28.3	.44	30.5	.44	32.1	.32	33.3	.24	9
	xxx	25.4	28.4	.40	30.0	.32	31.2	.24	32.2	.20	33.0	.16	17
101 to 140	o	58.9	61.5	.52	64.2	.54	66.9	.54	69.7	.56	72.5	.56	6
	x	49.4	51.8	.48	53.5	.34	55.0	.30	56.4	.28	57.5	.22	4
	xx	55.8	57.9	.42	60.0	.42	61.9	.38	63.5	.32	65.0	.30	4
	xxx	46.4	47.8	.28	49.0	.24	50.0	.20	50.6	.12	51.2	.12	4
201 to 240	o	75.5	76.7	.24	77.8	.22	78.9	.22	80.0	.22	81.2	.24	5
	xxx	71.4	72.0	.12	72.5	.10	73.0	.10	73.5	.10	74.0	.10	5

TABLE 10.—*Comparison of the average volume growth or increment of 102 felled western yellow pine trees, for a 25-year period, grouped by age classes and degree of mistletoe infection.*

Age class.	Degree of infection.	Total volume.		Increment, 1890–1895.		Total volume.	Increment, 1895–1900.		Total volume.
		1890.	1895.	Periodic annual.		1900.	Periodic annual.		1905.
Years.		*Cubic feet.*	*Cubic feet.*	*Cubic feet.*	*Per cent.*	*Cubic feet.*	*Cubic feet.*	*Per cent.*	*Cubic feet.*
21 to 60	o	0.36	0.54	0.036	(1)	0.80	0.052	(1)	1.19
	x	.02	.05	.006	.....	.20	.030	.....	.41
	xx	.01	.02	.002	.....	.08	.012	.....	.14
	xxx	.....	.....	.....	.....	.04	.008	.....	.08
61 to 100	o	3.77	5.40	.326	8.6	7.54	.428	7.9	10.23
	x	4.90	5.91	.202	4.1	7.10	.238	4.0	8.49
	xx	2.53	3.24	.142	5.6	3.98	.148	4.6	4.81
	xxx	4.12	4.94	.164	4.0	5.72	.156	3.2	6.46
101 to 140	o	35.10	39.78	.936	2.7	44.80	1.004	2.5	50.26
	x	25.95	30.15	.840	3.2	34.80	.930	3.1	39.20
	xx	23.72	26.35	.526	2.2	28.62	.454	1.7	30.75
	xxx	20.02	21.04	.204	1.0	22.87	.366	1.7	24.10
202 to 240	o	59.06	63.94	.976	1.7	69.38	1.088	1.7	75.72
	xxx	52.16	54.36	.440	.8	56.56	.440	.8	58.94

Age class.	Degree of infection.	Increment, 1900–1905.		Total volume.	Increment, 1905–1910.		Total volume.	Increment, 1910–1915.		Basis.
		Periodic annual.		1910.	Periodic annual.		1915.	Periodic annual.		
Years.		*Cubic feet.*	*Per cent.*	*Cubic feet.*	*Cubic feet.*	*Per cent.*	*Cubic feet.*	*Cubic feet.*	*Per cent.*	*Trees.*
21 to 60	o	0.078	(1)	1.81	0.124	(1)	2.67	0.172	(1)	11
	x	.042	.....	.86	.090	.....	1.25	.078	.....	6
	xx	.012	.....	.24	.020	.....	.37	.026	.....	7
	xxx	.008	.....	.18	.020	.....	.29	.022	.....	5
61 to 100	o	.538	7.1	13.52	.658	6.4	17.28	.752	5.6	12
	x	.278	3.9	9.89	.280	3.3	11.49	.320	3.2	7
	xx	.166	4.2	5.65	.168	3.5	6.52	.174	3.1	9
	xxx	.148	2.6	7.12	.132	2.0	7.70	.116	1.6	17
101 to 140	o	1.092	2.4	56.48	1.244	2.5	63.41	1.386	2.5	6
	x	.880	2.5	43.72	.904	2.3	48.07	.870	2.0	4
	xx	.426	1.5	32.70	.390	1.3	34.60	.380	1.2	4
	xxx	.246	1.1	25.32	.244	1.0	26.42	.220	.9	4
201 to 240	o	1.268	1.8	82.46	1.348	1.8	90.12	1.532	1.9	5
	xxx	.476	.8	61.38	.488	.8	64.00	.524	.9	5

[1] The periodic annual increment per cent was not computed for the 21 to 60-year age class because of the extremely small initial volumes and the proportionately great effect on the percentage of slight individual variations.

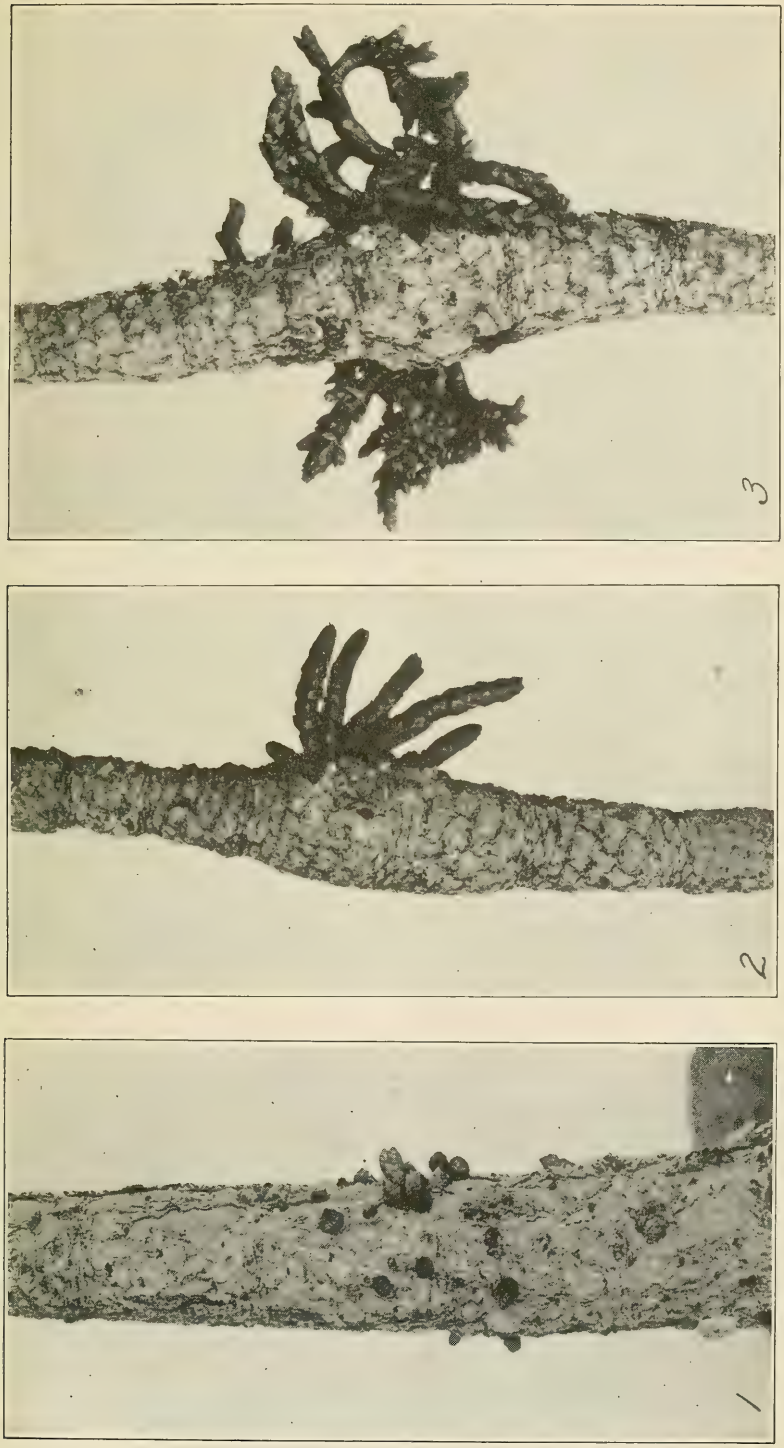
In the early stages of the study the trees were segregated by crown classes. Since by far the greater part of the trees in the open park-like stands studied were in the isolated, dominant, and codominant classes, the effects of crown class were found to be negligible in contrast to the marked effect of mistletoe in retarding the rate of growth. The retardation of growth due to the mistletoe was consistently evident in each age-crown class in which sufficient trees were secured to form a comparable basis. It was impossible to secure an equal number or equal proportion of each crown class in each age-infection class. As has been shown, it was found more necessary to segregate the felled trees by age-infection classes than by crown-infection classes. It was impracticable to segregate by crown classes all of the trees used in this study because of the extremely small number and in some cases entire lack of trees falling into each age-infection-crown class, had such a triple classification been used. The diameter, height, and volume growth during the 5-year period, 1910–1915, in the 21 to 60 year age class of the isolated trees included in Table 7, may be cited to show the injurious effect of mistletoe on growth within a given age-crown class, as follows:

Degree of infection.	Breast high diameter growth for last 5 years.	Height growth for last 5 years.	Volume growth for last 5 years.	Basis.
	Inches.	*Feet.*	*Cubic feet.*	*Trees.*
o	1.3	3.3	2.04	3
x	.8	2.0	.54	2
xx	.6	1.2	.25	3
xxx	(1)	.5	.004	4

[1] The trees in this class were less than 4.5 feet in height.

In Table 11 is shown increment data for two intensive sample plots aggregating 24 acres, located within the extensive plot on the Tusayan National Forest mentioned below, the data being grouped according to degree of infection. An accelerated growth is noted in the x infection class comparable to that noted in Table 1, the explanation of which is not evident from the data at hand, unless it be an actual stimulation due to the presence of the mistletoe. The decrease in the rate of growth in the heavily infected class is very marked and is in accord with all of the other results secured in this study.

Two seedlings, one healthy and the other heavily infected with mistletoe, which were growing side by side on a good site, were analyzed and both found to be 15 years old. The healthy seedling showed marked vigor and was 4 feet tall, whereas the one infected with mistletoe was only 3 feet tall and showed evident stunting and that death was imminent.



Three successive stages in the early development of mistletoe on twigs of western yellow pine and the formation of swellings by mistletoe.

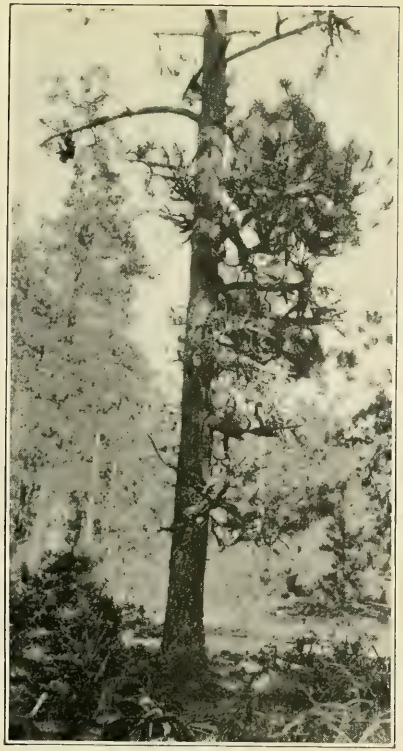


FIG. 1.—A western yellow pine tree showing stunted branches and witches' brooms in the lower part of the crown caused by mistletoe. Santa Fe National Forest, New Mexico.

FIG. 2.—Two "black jacks" in the foreground and a "yellow pine" in the background killed by mistletoe. The "black jacks" were killed recently while the "yellow pine" has been dead for a number of years. Coconino National Forest, Arizona.

FIG. 3.—A western yellow pine tree recently killed by mistletoe. Coconino National Forest, Arizona.

The data presented in the preceding pages show that, although minor fluctuations are exhibited, the rate of growth of the host decreases with the amount of mistletoe infection; or, in other words, is dependent on the degree of parasitism. Possible exceptions may be cases of very light infection which appear to act as stimulants for the host tree. These results are really to be expected when the effects of mistletoe parasitism are fully understood.

TABLE 11.—*The effect of mistletoe infection on the rate of growth of western yellow pine on two intensive sample plots aggregating 24 acres on the Tusayan National Forest.*

Degree of infection.	Average diameter growth, 1914–1919.	Periodic annual increment, 1914–1919.	Periodic annual increment, 1914–1919.[1]	Total volume of class, 1919.	Basis (number of trees, 4 inches and over d. b. h.).
	Inches.	*Cubic feet.*	*Per cent.*	*Cubic feet.*	
o	0.70	4.56	2.54	1,636.2	359
x	.88	5.65	2.79	553.9	98
xxx	.49	2.23	1.83	254.5	114

[1] On cubic-foot basis.

NOTE.—Since there were only 13 trees classed as moderately infected, they were omitted because of the small basis.

EFFECT ON LIMBS.

The first visible effect of the infection of a limb by mistletoe is the formation of a fusiform swelling (Pl. II) about the center of infection similar to those occasionally found on stems. This hypertrophy is the first stage of a later abnormal growth of branches from the enlarged portion, which results in the formation of witches' brooms. (Pl. III, Fig. 1.) When the stimulus of the parasite has once become manifest through the formation of a broom, the tendency toward abnormal branching continues, although the aerial parts of the mistletoe have may died.

The comparative diameter growth or accretion of 54 limbs on 18 standing black jacks is averaged by infection classes in Table 12. Measurements were taken at 6 inches from the bole of the tree and at 6-inch intervals beyond this point. The measurements taken at 6 to 18 inches from the bole of the tree were averaged and are presented in the table to facilitate a clearer and more comprehensive interpretation of the significant data. Limb measurements were also taken on the felled trees to check the comparative growth of the healthy and mistletoe-infected limbs of the standing trees. From these data, which are summarized in Table 13, it is apparent that the limbs had been infected at least 25 years prior to the time at which they were analyzed. The data presented in both tables show that, for the limbs examined, the rate of growth in diameter of limbs infected with mistletoe is greater than that of uninfected limbs. It is

very probable that the increased diameter growth continues to a certain point, beyond which there is a pronounced decrease in the rate of growth, until the limb eventually dies. This increased diameter growth is probably caused by the formation of an excessive amount of pathological parenchyma tissue, as a result of the irritation of the cambium by the parasite. The softer parenchyma adjacent to the center of infection renders the infected wood somewhat weaker than the more highly-lignified tissues of normal, uninfected wood. The presence of the mistletoe in the limb produces a stimulated growth of the host near the center of infection.

TABLE 12.—*Comparison of the average diameter growth or accretion of 54 limbs on 18 standing black jacks, for a 5-year period, grouped according to degree of mistletoe infection.*

Degree of infection.	Average diameter.[1]		Accretion, 1910–1915.		Basis.
	1910	1915	Periodic.	Periodic annual.	
	Inches.	*Inches.*	*Inch.*	*Inch.*	*Limbs.*
o	3.84	3.98	0.14	0.028	20
x	3.90	4.06	.16	.032	6
xx	4.35	4.62	.27	.054	7
xxx	4.08	4.46	.38	.076	21

[1] Average of two sets of measurements taken at 6 and 18 inches from the bole of the tree.

TABLE 13.—*Comparison of the average diameter growth or accretion of 8 limbs on 4 felled western yellow pine trees, for a 25-year period, grouped according to degree of mistletoe infection.*

Degree of infection.	Average diameter.[1]		Accretion, 1890–1895.	Average diameter.[1]	Accretion, 1895–1900.	Average diameter.[1]	Accretion, 1900–1905.	Average diameter.[1]	Accretion, 1905–1910.	Average diameter.[1]	Accretion, 1910–1915.	Basis.
	1890	1895	Periodic annual.	1900	Periodic annual.	1905	Periodic annual.	1910	Periodic annual.	1915	Periodic annual.	
	In.	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*Limbs*
o	1.68	1.84	0.032	2.01	0.034	2.21	0.040	2.34	0.026	2.46	0.024	4
xxx	3.06	3.32	.052	3.68	.072	4.04	.072	4.34	.060	4.56	.044	4

[1] Average of two sets of measurements taken at 6 and 18 inches from the bole of the tree.

Eccentricities, especially hyponastic growth, are considerably more pronounced in limbs heavily infected with mistletoe than in healthy limbs. The formation of a large witches' broom produces an abnormally heavy load which must be borne by that portion of the limb nearest to the bole of the tree. This abnormal load produces stresses sufficient to stimulate the formation of wood on the under side of the limbs through the deposition of food materials, which enables the wood to withstand the compression below. The tension above is over-

come by the development of a special tissue on the upper side of the limb.

The increased size of the limbs infected with mistletoe renders limbing and brush disposal in logging operations more difficult and consequently more expensive. The excessive secretion of resin which occurs in mistletoe-infected limbs has somewhat the same effect on brush disposal.

HYPERTROPHY AND RESIN FLOW.

Although mistletoe infection causes swellings on both branches and trunks, the stem swellings frequently become less noticeable as the tree grows. In many cases there are no pronounced swellings on the larger boles even when very old mistletoe infections are present, about the only means of detecting the infection being the presence of the mistletoe or the unusual roughness of the bark. (Pl. IV, Fig. 1.) When, however, infection occurs during the early life of the tree, it frequently results in the formation of a burl which may attain very conspicuous proportions. The fusiform swellings on both the stems and limbs resulting from mistletoe infections are centers where abnormal amounts of food materials are stored, which condition is evidently stimulated by the decided pathogenic tendencies of the mistletoe. The cortex is frequently gnawed from the lesions by rodents, especially porcupines and squirrels, attracted by the soft spongy nature and the greater thickness of the inner bark of mistletoe-infected branches and stems. This fact establishes a casual relationship between mistletoe infection and rodent injury.

As previously stated, there is more or less hypertrophy at the point of mistletoe infection on both limbs and stems. This hypertrophy is frequently accompanied by a copious flow of resin, which appears as small drops, usually on the lower side of limbs, which are heavily infected with mistletoe. A cross section through such a limb shows large areas of the sapwood thoroughly infiltrated with resin. The process of infiltration continues on many of the limbs until the fibrovascular system is thoroughly clogged with resin; the limb is girdled as far as receiving any food supply is concerned, and is finally killed. This process is usually very gradual, but none the less sure.

The resin flow from such mistletoe-infected limbs is not caused by insect punctures. A careful examination of the resin-infiltrated areas fails to show any signs of such injury. On many of the trees which are heavily infected with mistletoe, resin cankers (Pl. IV, Fig. 2) of varying sizes are found on the bole. These cankers are often directly associated with local mistletoe infection. The resin flows on the bole are usually indicative of the decline of the tree; in fact, trees with marked resin-flow cankers usually die in a relatively short time.

EFFECT ON THE FOLIAGE.

Tables 14, 15, and 16 show the effects of the mistletoe on the foliage of the western yellow pine. The data included in Table 16 were obtained as follows:

Each tree crown was divided into three divisions—bottom, middle, and top—including in each division about one-third of the total leaf surface. One hundred tufts from each section were selected at random and measured; the mean length of these tufts was taken as the average length per tuft for that section. Then 10 tufts of this average length were taken from each of the three sections into which the crown had been divided. These tufts, 30 in all for each tree, were cut off and taken to the laboratory, where the number of leaves per tuft, the length, and the width of each leaf were determined. The total number of tufts in the bottom, middle, and top thirds was determined by actual count. The number of tufts thus obtained was multiplied by the average number of leaves found in the 10 tufts from each section. This gave the average number of leaves in each section. The sum of the leaves in the three sections gave the average number of leaves in any given tree crown.

TABLE 14.—*Comparison of the length of leaves of 103 western yellow pine trees, classified according to degree of mistletoe infection.*

Degree of infection.	In lower portion of crown.			In central portion of crown.			In upper portion of crown.			Mean for entire crown.			Basis.
	Mean minimum.	Mean Maximum.	Average.	Mean minimum.	Mean maximum.	Average.	Mean minimum.	Mean maximum.	Average.	Mean minimum.	Mean maximum.	Average.	
	In.	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*Trees.*
o	3.3	6.2	4.9	3.8	6.3	5.5	4.2	6.9	5.8	3.8	6.5	5.4	38
x	2.3	5.3	4.0	2.5	5.9	4.5	3.3	6.2	5.0	2.7	5.8	4.5	15
xx	2.1	5.3	3.8	2.5	5.4	4.1	2.9	5.7	4.6	2.5	5.5	4.2	18
xxx	2.1	5.1	3.6	2.4	5.1	4.0	2.7	5.1	4.0	2.4	5.1	3.9	32

TABLE 15.—*Comparison of the length of leaf tufts of 97 western yellow pine trees, classified according to degree of mistletoe infection.*

Degree of infection.	In lower portion of crown.			In central portion of crown.			In upper portion of crown.			Mean for entire crown.			Basis.
	Mean minimum.	Mean Maximum.	Average.	Mean minimum.	Mean maximum.	Average.	Mean minimum.	Mean maximum.	Average.	Mean minimum.	Mean maximum.	Average.	
	In.	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*Trees.*
o	3.4	11.5	6.7	5.4	15.5	10.0	6.8	22.7	13.8	5.2	16.6	10.2	37
x	3.0	10.1	6.5	4.0	12.0	8.0	5.5	16.8	10.3	4.2	13.0	8.3	15
xx	2.4	8.2	4.9	2.3	9.1	5.2	3.4	11.1	7.3	2.7	9.4	5.8	15
xxx	2.3	8.1	4.5	2.6	8.6	5.0	2.4	8.5	4.8	2.4	8.4	4.8	30

FIG. 2.—A resin canker developing in an old mistletoe lesion on western yellow pine.

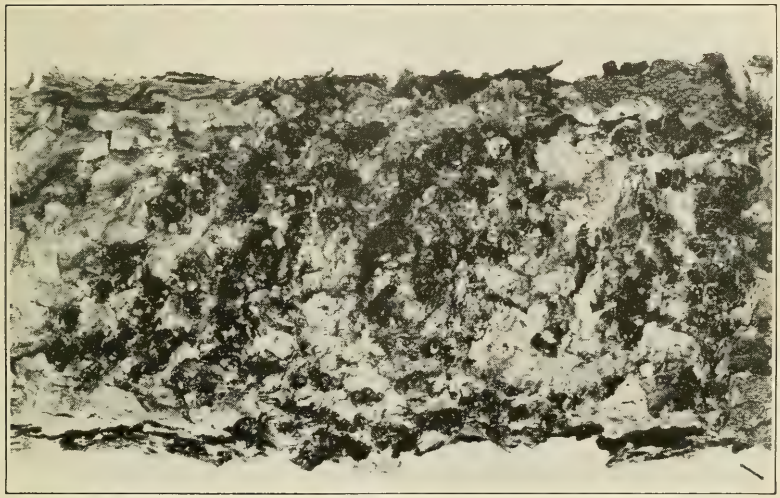


FIG. 1.—Concentric rings of advance of a mistletoe lesion on western yellow pine.

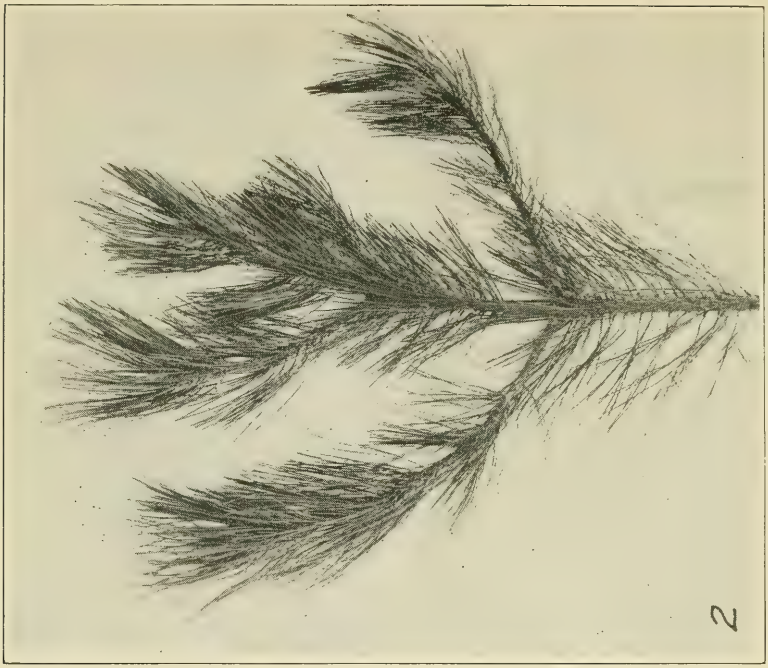


FIG. 2.—A small branch of western yellow pine showing the larger leaves and longer internodes developed on a healthy tree in the same group from which the branch shown in Figure 1 was secured. One-eighth natural size.

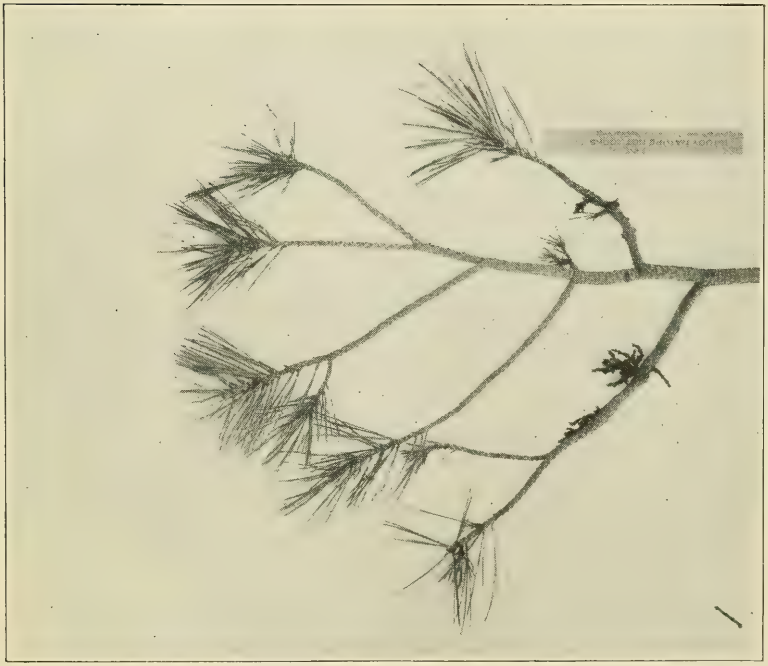


FIG. 1.—A small branch of western yellow pine showing fewer and smaller leaves and shorter internodes due to the mistletoe, of which three local infections may be seen. One-sixth natural size.

TABLE 16.—*The effects of mistletoe on the photosynthetic surface of western yellow pine.*

Tree number.	Degree of infection.	Age.	Diameter breast high outside bark.	Total height.	Total volume.	Crown.		Crown class.
						Width.	Length.	
		Years.	*Inches.*	*Feet.*	*Cubic feet.*	*Feet.*	*Feet.*	
103	xxx	80	7.5	20.0	2.50	10.0	15.5	X
104	o	79	14.5	42.0	19.00	17.0	32.0	X
105	xxx	83	8.1	26.0	3.55	8.5	18.5	C
106	o	83	15.2	49.0	22.50	22.0	42.0	C
107	o	37	7.1	21.0	2.40	12.0	18.0	D

Length of leaf tufts.

Tree number.	Lower portion of crown.				Center of crown.				Upper portion of crown.				Mean for entire crown.		
	Minimum.	Maximum.	Average.	Number of tufts.	Minimum.	Maximum.	Average.	Number of tufts.	Minimum.	Maximum.	Average.	Number of tufts.	Minimum.	Maximum.	Average.
	In.	*In.*	*In.*		*In.*	*In.*	*In.*		*In.*	*In.*	*In.*		*In.*	*In.*	*In.*
103	0.5	7.0	3.2	81	1.0	8.0	3.8	329	1.0	12.0	5.7	234	0.8	9.0	4.2
104	1.0	11.3	5.3	2,161	2.0	13.0	5.4	2,390	2.0	18.0	8.0	1,151	1.6	14.1	6.2
105	.3	11.0	3.7	242	.5	12.0	4.0	183	.6	13.0	5.0	176	.4	12.0	4.2
106	1.0	11.0	4.0	1,522	1.5	17.0	6.7	1,228	2.0	26.0	7.7	445	1.5	18.0	6.1
107	1.5	12.5	6.8	379	2.5	18.0	8.8	321	2.5	28.0	10.0	313	2.1	19.5	8.5

Tree No.	Total number of tufts in entire crown.	Length of leaves.							
		Lower portion of crown.				Center of crown.			
		Mean minimum.	Mean maximum.	Mean average.	Number of leaves.	Mean minimum.	Mean maximum.	Mean average.	Number of leaves.
		In.	*In.*	*In.*		*In.*	*In.*	*In.*	
103	644	1.6	3.3	2.6	13,122	1.7	3.5	2.6	62,181
104	5,702	2.5	4.9	3.5	518,640	2.8	5.1	3.7	803,040
105	601	2.0	4.1	3.2	109,142	2.3	4.2	3.1	67,161
106	3,195	4.1	5.8	4.9	365,280	4.4	6.7	5.7	289,808
107	1,013	3.3	5.2	4.5	94,371	4.1	5.7	5.1	172,972

Tree No.	Length of leaves.						
	Upper portion of crown.				Mean for entire crown.		
	Mean minimum.	Mean maximum.	Mean average.	Number of leaves.	Mean minimum.	Mean maximum.	Mean average.
	In.	*In.*	*In.*		*In.*	*In.*	*In.*
103	1.8	4.5	3.2	84,240	1.7	3.7	2.8
104	2.8	5.1	4.1	470,759	2.7	5.0	3.7
105	3.1	5.0	4.3	85,712	2.4	4.4	3.5
106	4.8	6.8	5.9	182,005	4.4	6.4	5.5
107	5.2	6.4	5.9	152,431	4.3	5.7	5.1

TABLE 16.—*The effects of mistletoe on the photosynthetic surface of western yellow pine*—Continued.

Tree No.	Total number of leaves in entire crown.	Leaf surface.				Ratio of leaf surfaces.	Ratio of volumes.[1]
		Lower portion of crown.	Central portion of crown.	Upper portion of crown.	Entire crown.		
		Square inches.	*Square inches.*	*Square inches.*	*Square inches.*		
103	159,543	4,094.1	19,400.4	32,348.2	55,842.7	1.0	1.0
104	1,792,439	217,828.8	356,549.8	231,613.4	805,992.0	14.4	7.6
105	262,015	40,910.5	24,983.9	44,427.4	110,321.8	2.0	1.4
106	837,093	218,438.4	198,228.7	128,939.5	545,606.6	9.8	9.0
107	419,774	50,960.3	105,868.9	107,921.4	264,750.6	4.7	.96

[1] In these ratios Tree No. 103 is taken as unity.

The average length and width of the leaves in the 10 tufts selected were used in determining the leaf surface for a given section of the crown, and this in turn for finding the total leaf surface of a given tree. Table 16 shows that not only does the mistletoe shorten the length of both leaf tufts and leaves, but it also materially decreases the number of leaf tufts per tree for heavily infected trees when compared with healthy trees of the same age and site conditions. (Pl. V.) When two trees of the same size, one healthy and the other heavily mistletoed, are compared—Trees No. 103 and No. 107, for instance—it is seen that it has taken the mistletoe-infected tree more than twice the number of years to reach the same size as the healthy tree. The average ratio of the leaf surface in square feet to the total volume in cubic feet for the healthy trees given in Table 16 is 409.7 compared with 185.5 for the heavily infected trees.

Trees heavily infected with mistletoe not only have considerably shorter leaves and leaf tufts than healthy trees, but the leaves of mistletoe-infected trees are lighter in color than those of healthy trees, being a yellowish green as compared with the olive green on the healthy trees. Each heavy infection causes a localization and reduction of the photosynthetic or assimilatory leaf surface of the tree, which in turn results in a marked decrease in the rate of growth.

EFFECT ON LONGEVITY OF HOST.

A number of permanent sample plots were established on the Coconino and Tusayan National Forests by the Fort Valley Forest Experiment Station, in 1909, to determine the rate of growth and decadence, the rate of establishment of natural reproduction, and the effect of various factors upon regeneration on cut-over areas. These plots were remeasured in 1914 and 1919. Some of the plots yielded valuable data on the amount of mistletoe infection and the resulting mortality on cut-over areas.

On an area of 456 acres on the Tusayan National Forest about 5 miles from the Fort Valley Forest Experiment Station, 2,636 black jacks, or 34.9 per cent of the total number on the plot, and 225 yellow pines, or 34.8 per cent of the total number, were infected with mistletoe in 1914. In 1919, 2,335 black jacks, or 28.8 per cent of the total number of trees 4 inches in diameter and over, were infected with mistletoe. In many instances the infection was not sufficient to render the tree unhealthy, but with the increase of infection many of the infected trees will pass through the various infection classes and eventually die.

All of the trees which had died on the plots during the two 5-year periods were carefully examined and the cause of death noted. On the plot of 456 acres on the Tusayan National Forest 170 black jacks died from various causes during the first 5-year period, or 2.2 per cent of the total number of black jacks living on the plot in 1909, while 21 yellow pines died during the 5 years, which is 3.4 per cent of the total number of yellow pines living on the area. During the 5-year period from 1914 to 1919, 127 black jacks died from mistletoe alone, or in conjunction with other agents such as insects, porcupines, etc.

On a plot of 135 acres located on the Coconino National Forest about 1½ miles from the Fort Valley Forest Experiment Station, 27 black jacks died from various causes during the first 5 years, which is 1.1 per cent of the total number of black jacks living on the plot in 1909; 26 yellow pines, or 1.8 per cent of the total number, died during the same period.

A digest of that part of the detailed records pertaining to mistletoe as a cause of the death of western yellow pine during the 5-year period from 1909 to 1914 is given in Table 17. The 456-acre plot on the Tusayan National Forest is located on an area which has sustained heavy losses from mistletoe, while the 135-acre plot on the Coconino is located on an area with only occasional heavy infections. A study of Table 17 indicates the mortality of western yellow pine on these two areas and the extent to which mistletoe was a direct cause or a contributing factor. A study of Table 17 also indicates that of the 170 black jacks on the Tusayan plot which died during the 5-year period 26.4 per cent were killed directly by mistletoe, 42.3 per cent by mistletoe combined with other agents, and only 31.3 per cent died from other causes; while only 4.8 per cent of the yellow pines were killed by mistletoe combined with bark beetles. On the 135-acre Coconino plot mistletoe infection alone resulted in the death (Plate III, Fig. 2) of 7.5 per cent of the total number of dead blackjacks and 7.9 per cent of the total number of dead yellow pines, while mistletoe was a contributing factor toward the death of an additional 20.2 per cent of the yellow pines. During the 5 years 1.5 per cent

of the total number of black jacks on the Tusayan plot in 1909 were killed by mistletoe alone or in conjunction with other agents, mainly insects. While this figure itself is not high, it is alarming because the indications are that the death rate will increase from year to year, and although an effort was made to have all heavily infected trees removed when this area was marked for cutting, it is evident that mistletoe did not receive the attention which it deserved.

TABLE 17.—*Classification of dead trees on permanent sample plots of 456 acres on the Tusayan and 135 acres on the Coconino National Forest.*

Cause of death.	Per cent of dead trees, 1909–1914 (based on total number of trees which died during 5-year period).			
	456-acre plot, Tusayan National Forest.		135-acre plot, Coconino National Forest.	
	Black jack.	Yellow pine.	Black jack.	Yellow pine.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
Mistletoe	26.4	.....	7.5	7.9
Mistletoe and insects	35.0	4.8	.....	20.2
Mistletoe and porcupine	5.5	.....	.....	.....
Mistletoe and suppression	1.4	.....	.....	.....
Mistletoe, porcupine, and insects	.4	.....	.....	.....
All other causes	31.3	95.2	92.5	71.9
Total	100.0	100.0	100.0	100.0

Weir [4] has noted the same direct relation between mistletoe infection and insect infestation in the Northwest, especially with *Dendroctonus valens*. The origin of numerous insect infestations has been traced to stands of western yellow pine heavily infected with mistletoe.

The main difference between mistletoe and insect injury is in the length of time required for the injury to become manifest. A sporadic insect infestation may develop rapidly and may kill a large number of trees in a relatively short time, and it may even continue to increase until it is overcome and reduced to normal proportions through some natural agency. Mistletoe, on the other hand, develops slowly but continuously and persistently. The bark beetles, when attracted by the resinuous exudations of the mistletoe-infected trees, may materially hasten the death of the host which has already been weakened by the parasitic mistletoe. Trees dead or dying from mistletoe infection have been found infected with species of secondary bark beetles and borers, such as Ips, Pityophthorus, Chrysobothris, and Melanophila.

Three black-jack saplings under 4 inches in diameter breast high on one of the intensive mistletoe-study plots died during the five-year

[4] Weir, James R., Mistletoe Injury to Conifers in the Northwest. U. S. Dept. Agri. Bulletin 360, 39 pp., 1916.

period as a direct result of mistletoe infection. Five yellow pines on the same area were also killed by mistletoe during the same period. Many of the other trees on the sample plots, although not dead at the last examination, were small and stunted; they were making an almost inappreciable growth and were very unhealthy in appearance. Some of these, which are apparently unable to endure the parasitism of the mistletoe combined with a rather adverse climate, will undoubtedly succumb before the remeasurement of the plots at the end of the next five-year period. Practically all of the trees which are heavily infected with mistletoe are ultimately doomed, since it is only a question of the length of time during which they can withstand the insidious action of the parasite.

EFFECT OF MISTLETOE ON MERCHANTABILITY OF TIMBER.

Although the mistletoe injury to the host results less in the depreciation of the lumber than in the impairment of the vital physiological functions of the tree, there is nevertheless an appreciable effect on the quality of the lumber. The accelerated growth of mistletoe-infected limbs, as shown in Tables 12 and 13, results in larger limbs which produce knots of a larger size in the lumber that is sawed from the boles of the mistletoe-infected trees. The number of knots is also increased by the greater number of secondary branches and twigs in stem infections. The increased size and number of the knots may, in many cases, be sufficient to lower materially the grade of the lumber.

Mistletoe-infection produces a curly or abnormally grained wood and weaker lumber. Wood invaded by the thread-like sinkers of the mistletoe is spongy, and is frequently discolored and pitchy, as a result of the resinous flow or bleeding of the trees. The presence of mistletoe burls renders a tree more susceptible to wind breakage; in addition, it may ruin a portion or all of a sawlog. A seedling or sapling whose stem is infected with mistletoe will seldom develop a bole large enough to yield any considerable quantity of lumber and very rarely, if at all, lumber of a high grade. It is therefore evident that, aside from the physiologically injurious effect of the mistletoe, it also introduces a cull factor in that mistletoe-infected trees produce a poorer grade of lumber than healthy trees.

EFFECT OF MISTLETOE ON SEED PRODUCTION OF HOST.

Pearson [5] has shown that, as a result of a collection in 1909, seed from mistletoe-infected black jacks gave a germination of 17 per cent below that of healthy black jack, which had a final germination of 78 per cent. The present study leads to the conclusion that,

[5] Pearson, G. A. The Influence of Age and Condition of the Tree Upon Seed Production in Western Yellow Pine. U. S. Dept. of Agri., Forest Service Cir. 196, 1912.

although the mistletoe may stimulate growth in that portion of the host adjacent to the parasite, causing the abnormal development of certain limbs and branches into witches' brooms, the excess of carbohydrates produced by the additional foliage of the mistletoe-stimulated branches is consumed by the parasite, thereby reducing the amount available for the seeds. The effect upon the host in all cases is insidious, slowly depriving the tree of its vitality instead of causing injuries in the nature of a shock, as in the case of burns and other mechanical injuries. In this and the following study, no information was available as to the influence upon seed production of the condition of other trees which may have supplied the pollen for fertilizing the seed tree. Because of the lack of pollination experiments, the conclusions are necessarily based wholly upon the condition of the tree from which the seed was collected.

In order to check this theory further, additional seed collections were made by the Fort Valley Forest Experiment Station in 1913 and 1915 from mistletoe-infected and healthy western yellow pines. Aside from the difference in degree of mistletoe infection, the trees were otherwise normal and very similar in age and crown development. The seed extractions and germination tests were conducted separately for each tree. Five hundred seeds from each lot were germinated in sand in the greenhouse at a temperature ranging from 40° to 90° F., with a mean daily temperature of approximately 65° F. Daily counts were made during the progress of the germination tests, which continued for approximately 50 days.

The pertinent data on the seed-production of 64 felled western yellow pine trees for the 1913 and 1915 collections are classified in Table 18, according to the degree of mistletoe infection. The best criterion by which to judge the relative seed production is believed to be the reproductive value of each tree or the total number of viable seeds produced per tree, which represents a convenient summation of the fundamental variables of seed production. This is obtained by multiplying the yield per tree in pounds of clean seed by the number of clean seeds per pound, and in turn multiplying the product by the final germination per cent. It will be noted that, with the exception of the lightly infected class upon which the mistletoe appears to have a slight stimulating effect, there is a decrease in the percentage of germination, the yield of cones, and clean seed per tree and consequently a marked decrease in the reproductive value per tree with an increase in the amount of mistletoe infection. The reproductive value of the trees in the intermediate infection class is about 40 per cent of that of the healthy class, while the reproductive value of the trees in the heavily infected class falls to only about 25 per cent of that of the healthy class. This is not surprising when the effects of the parasitism are fully understood. The data for the mistletoe-infected classes of

felled trees reported in Table 18 are meager because of the difficulty experienced in securing seed from mistletoe-infected trees, owing to the sterility of the cones and their failure to develop. In fact, a diligent search was made for heavily mistletoed trees which were bearing seed, but very few were found.

TABLE 18.—*Data on the seed production of 64 felled western yellow pine trees classified according to degree of mistletoe infection.*

Degree of infection.	Final germination.	Clean seeds per pound.	Yield per tree.		Reproductive value per tree.	Basis.
			Cones.	Clean seed.		
1913 collection:	*Per cent.*	*Number.*	*Bushels.*	*Pounds.*	*Number of viable seeds.*	*Number of trees.*
o	82.8	14,473	0.8	1.08	12,942	43
x	84.1	14,385	1.0	1.10	13,292	2
xx	81.7	13,314	.5	.45	4,895	2
xxx	77.0	14,475	.3	.31	3,455	2
Mean of x, xx, and xxx	80.9	14,058	.6	.62	7,052	6
1915 collection:						
o	53.2	12,156	1.1	.83	5,626	11
Mean of x, xx, and xxx	47.1	14,170	.9	.37	2,202	4

The extent and condition of the seed crop on the standing trees on the permanent sample plots were under observation from 1912 to 1916 in order to secure additional data on the effect of mistletoe infection on the amount and periodicity of seed production. The 1912 seed crop was rather light; only a few of the trees bore any large quantity of cones. In 1913 there was an average crop, with practically none in 1914, while the 1915 seed crop was somewhat below the average.

The records of the 1912 and 1915 seed crops for 90 of the living western yellow pines are classified in Table 19 by degree of mistletoe infection and amount of the seed crop. The seed crops were arbitrarily classified by the observer as heavy, good, medium, light, or none. An analysis of the data shows that the amount of seed production varies inversely with the degree of mistletoe infection. As the degree of mistletoe infection increases the amount of seed produced decreases until very little, if any, seed is produced by heavily infected trees.

These results are further substantiated by observations of the writers covering a period of approximately 10 years. Trees heavily infected with mistletoe produce small amounts of seed at such times as there are generally heavy seed crops, and at other times practically none. The few cones that may occasionally be found on trees heavily infected with mistletoe are very often aborted, and are frequently infested with a cone insect (*Conophthorus ponderosæ*).[6]

[6] Material determined by Office of Forest Insect Investigations, Bureau of Entomology, U. S. Dept. of Agriculture.

TABLE 19.—*Record of 1912 and 1915 seed crops for 90 standing western yellow pine trees classified by degree of mistletoe infection and amount of seed crop.*

Degree of infection.	Amount of seed crop.										Total basis.
	Heavy.		Good.		Medium.		Light.		None.		
	Number of trees.	*Per cent.*	*Number of trees.*	*Per cent.*	*Number of trees.*	*Per cent.*	*Number of trees.*	*Per cent.*	*Number of trees.*	*Per cent.*	*Trees.*
1912 seed crop:											
o.....	0	0	0	0	2	5.3	9	23.7	27	71.0	38
x.....	1	7.7	0	0	1	7.7	4	30.8	7	53.8	13
xx.....	0	0	0	0	0	0	5	25.0	15	75.0	20
xxx....	0	0	0	0	0	0	0	0	16	100.0	16
1915 seed crop:											
o.....	0	0	1	2.8	2	5.5	15	41.7	18	50.0	36
x.....	0	0	0	0	2	14.3	5	35.7	7	50.0	14
xx.....	0	0	0	0	0	0	4	18.2	18	81.8	22
xxx....	0	0	0	0	0	0	0	0	18	100.0	18

A similar deterrent effect of mistletoe on the seed production of Douglas fir, western larch, and lodgepole pine has also been found by Weir [7] to obtain in the Northwest, where seed collected from very old mistletoe brooms showed a germination on an average of 10 per cent below that of seed taken from uninfected branches of the same trees. Munns [8] reports that Jeffrey pine trees infected with mistletoe had half as many more seed to the pound as were found in the cones on thrifty trees, but the germination was 20 per cent lower and the seedlings produced were not so vigorous. It seems very improbable that moderate or heavy mistletoe infection would ever act as a stimulus upon seed production, because its slow, insidious action makes constantly greater demands upon the vitality of its host. Trees moderately or heavily infected with mistletoe are therefore of little or no value for the purpose of seed production.

The fact is fundamental in silviculture that variations in the individual characteristics of the parent trees are hereditarily transmitted through the seed.[9] The extent to which the origin of the seed influences such characteristics as the resistance or immunity to disease, the rate of growth, and the growth-form of the regenerated forest, is of vital importance in the rational practice of scientific forestry.

The experiments of Zederbauer [10] indicate that trees grown from seed collected from intermediate, suppressed, and weakened trees are less resistant to disease than trees grown from seed produced by dominant and vigorous trees. The hereditary characters of the species are not changed materially during one rotation. Several generations are necessary to show the true effects of those characteristics

[7] Weir, James R. Mistletoe Injury to Conifers in the Northwest. U. S. Dept. of Agri. Bul. 360, 1916.

[8] Munns, E. N. Effect of Fertilization on the Seed of Jeffrey Pine. Plant World, 22: 138–144, 1919.

[9] Engler, Arnold. Einfluss der Provenienz des Samens auf die Eigenschaften der forstlichen Holzgewächse. Mitteilungen der Schweizerischen Centralanstalt für das forstliche Versuchswesen, Zürich, 1905, B. 8, s. 81–236; 1913, B. 10, s. 1–386.

[10] Zederbauer, E. Centralblatt für das gesammte Forstwesen, 1912, s. 201.

of the parent tree which may be transmitted through the seed, such as an unusual divergence from the typical silvical characteristics of the species. A clearer conception of the latent possibilities of disease resistance and immunity of a species obtained through tree breeding is of vast importance in the silvicultural improvement and management of the forest. The hereditary influence of the parents upon the offspring is a well-recognized factor in genetics. This factor is doubly important in forestry, not only in the collection of seed for artificial regeneration, but also in the selection of seed trees to provide for the natural reproduction of cut-over forests. In timber-sale practice only thrifty seed trees should be left and all diseased and suppressed trees should be removed in order to improve the condition of the forests of the future.

SILVICULTURAL ASPECT OF MISTLETOE INFECTION.

The destruction caused by disease promises to approach or even surpass the losses from fire on the national forests of the Southwest, now that the development of fire protection has reduced the fire hazard. Mistletoe injury presents one of the most serious phases of this silvicultural problem. The parasite may be slow in effecting its injury, but it is unquestionably sure.

A brief discussion of some of the salient objects of silviculture is essential to a complete understanding of the significance of any methods of control which may be attempted. The chief fundamentals of silviculture, as applied in the regeneration of western yellow pine stands, are to maintain the continuity of the forest and to increase its productivity. A number of basic considerations must be taken into account under any rational method of cutting, among which may be mentioned the silvics of the species, the fire hazard and liability, exploitation and economic conditions, and the removal of the decadent, unhealthy, and overmature timber as rapidly as possible, to avoid waste through decay. All defective, diseased, and suppressed trees should be marked for cutting unless needed as fire insurance or seed trees. No defective or diseased tree should be left standing if it is evident that it will not live until the next cutting, unless it is absolutely required for silvicultural purposes. When it becomes necessary to reserve trees among the large diameter classes, thrifty, healthy trees of good form should be selected, since the condition of the progeny is influenced by heredity as well as by soil and climate. Increased forest productivity will be realized if, in the application of the above principles, the forester will also strive to eliminate the deterioration of merchantable material. It is thus evident that the marking on each individual area must be varied to meet the silvicultural requirements of the forest. The importance of careful, intelligent marking on timber-sale areas can not be over-

estimated, since this is the practicable means by which rational silvicultural management is actually secured.

Meinecke [11] has suggested the establishment of pathological rotations for species of economic importance which are subject to serious diseases. A pathological rotation may be defined as the period during which the timber crop may grow and be subject to exploitation at a profit, but beyond which rapid deterioration is imminent and the product will be marketed at a great reduction in value. The pathological rotation is therefore a limiting factor; and, with regard to heartwood-destroying fungi entering the heartwood through open wounds, it is based upon the age of decline or the age at which even unwounded trees become subject to heavy infection because they are unable to throw off the parasite or to hold its growth in check. From the discussion in the earlier part of this bulletin it will be seen that the mistletoe may kill small seedlings only a few years old, as well as veteran western yellow pines 200 to 300 years old. It is therefore evident that it would not be practicable to attempt to establish a pathological rotation for mistletoe-infected western yellow pine.

CONTROL OF MISTLETOE.

Any method of control of this serious and widely distributed enemy of the western yellow pine forests of the Southwest must be adapted to existing conditions. As in the case of other diseases, prevention is the basis for control. The protection of healthy stands of timber from disease is accomplished mainly by removing the source of infection.

Mistletoe is more susceptible to control measures than many fungi. Infection is confined to the aerial parts of the host, while fungi may infect the subterranean as well. The seeds of the mistletoe, which are much larger than the microscopic spores of fungi, are not subject to such wide dissemination. Mistletoe is killed with the death of its host, whereas certain fungi may remain alive for an indefinite period following the death of their hosts.

It is evident also that mistletoe develops rapidly after cutting, since many of the trees left standing on the permanent sample plots were killed by mistletoe during the five years following the logging operation; and many more, although still alive, will die in the course of a comparatively few years. In this study mistletoe was found to be directly or indirectly responsible for the greater number of deaths of western yellow pine.

All of the facts at hand indicate that the cutting of mistletoe-infected trees is the only practicable method of control. Since mistletoe appears to spread more rapidly and to grow faster on lightly infected trees, as a result of increased wind and light following

11 Meinecke, E. P. Forest Pathology in Forest Regulation. U. S. Dept. of Agri. Bul. 275, p. 59, 1916.

cutting and providing more favorable conditions for the optimum development of the parasite, every effort should be made to free the stand entirely of mistletoe infection, although it is doubtful whether in certain cases the removal of lightly infected trees would be warranted because of silvicultural reasons. The increased activity of the mistletoe following the opening of the stand militates against leaving for a future cutting operation any but lightly infected trees, the infection of which is confined to the lower portion of the crown. Old and heavily infected trees should be cut for two reasons: (1) To improve the hygienic condition of the forests of the future through the removal of the mistletoe, and (2) to secure the maximum realization on a rapidly diminishing growing stock or forest capital. Since the future productivity of the forests depends to a great extent upon the proper choice of seed trees or of the seed itself in the case of artificial regeneration, those trees used for reproductive purposes should be sound, healthy, and of an intermediate age class.

As heavy a stand of healthy trees as possible should be left in order to compensate for the removal of diseased trees, and to maintain better forest conditions, reduce wind damage, and insure a denser stand of reproduction. Exceptional care should be taken to leave every healthy black jack which is free from infection. Wherever possible, trees should be freed from light infections by cutting off lower branches within reach. Transition trees and vigorous yellow pines, suitable for seed trees, should be left in greater numbers to take the place of diseased black jacks removed, to maintain better forest conditions, and to furnish abundant seed for the restoration of the stand. Small heavily infected black jacks should be marked wherever it is possible to have them cut under the sanitation clause of the timber-sale contract, or where there is a market for small material, such as stulls, mine props, ties, poles, posts, and pickets.

Forest officers in charge of marking on mistletoe-infected timber-sale areas should study carefully the possibilities of increasing the number of healthy trees in the remaining stand. The pruning of infected limbs from small trees at the time of marking presents a practical means of eliminating light limb infections and at the same time increasing the number of healthy trees. Occasionally there are trees in a stand that are lightly infected on a low branch within reach of the ground. Mistletoe-infected reproduction and young timber below merchantable size should also be freed from the disease either through cutting the seedlings and saplings or by lopping off the infected branches. Such measures may be impracticable except on timber sale areas and in some cases the extra labor and expense involved may prove prohibitive.

The areas of mistletoe infection should be located and mapped as a prerequisite to an efficient control campaign. The degree of injury

and the amount of infection should also be recorded. Weir[13] has suggested that this could easily be done by timber-survey parties in connection with their regular mapping and cruising work. Such tangible records of mistletoe infections would be invaluable to forest officers in showing just where diseased stands are located, in order that an attempt be made to exploit stands of seriously diseased timber as rapidly as possible.

The advent of a large commercial timber-sale operation should not be awaited before undertaking mistletoe-control work. Small ranger sales and even the issuance of free-use permits would materially assist in the reduction of severe infections. Although in many instances the large lumbering operation is more economical than the small one, the latter can render a definite service in improving the hygienic condition of the forest through removing more or less isolated infections which are too small to be exploited in a large operation. The products of the small operation are not marketed in such highly finished or specialized form as are many of the products of the large operation. In the case of a small lumbering operation mistletoe-infected trees will, in almost every case, be as well adapted to the desired uses as the products of healthy trees.

The problem of the control of mistletoe assumes two quite different aspects, depending upon the degree of infection on a given area. Silvicultural systems of regeneration should provide for the eradication of the mistletoe from the stand as one of the most necessary results to be accomplished. On areas adequately stocked with advance reproduction all infected trees should be cut. On the other hand, on areas of light to moderate infection special emphasis should be laid upon the need of leaving all healthy trees possible, even if they belong to the "yellow-pine" class, in order to insure as good a condition of the forest cover and seed production as possible. Where the injury is not very serious the marking rules should call for the removal of all mistletoe-infected trees possible without breaking up the continuity of the stand or materially interfering with the silvicultural system of management adopted for the area. Lightly infected areas should be marked in such a manner that, with supplemental pruning at the time of marking, the stand would be practically free of infection. Lightly infected black jacks and transition trees on areas bearing no advance reproduction should not be cut when otherwise thrifty and sound, except where thinnings are desirable to obtain increased growth or where reproduction is established. Such thinnings, however, may be somewhat heavier than in uninfected stands; but in lightly infected black-jack stands where reproduction is not established vigorously growing and thrifty trees should not be radically sacrificed.

[13] Weir, James R. Some Suggestions on the Control of Mistletoe in the National Forests of the Northwest. Forestry Quarterly, 14: 567–577, 1916.

Lightly infected yellow pines should be left when uninfected trees or lightly infected black jacks are not available for seed and protection.

Moderately infected trees should always be marked for cutting, except where there are no other trees available to leave as seed trees. Mistletoe can not in all cases be eliminated in one cutting without too great a sacrifice of silvicultural requirements. Moderately infected trees should not be left for seed on lightly infected areas if healthy trees are available within 100 yards. This, however, applies to large areas rather than to small openings or small areas which have a chance to seed in from surrounding trees and where infection might be removed completely without opening the forest too extensively. Moderately infected trees should be left for soil-protection purposes only on the most adverse sites, where their need for this purpose is clearly evident.

Areas of heavy infection on which the injury from mistletoe is alarming should receive special attention and should be treated from the standpoint of the sanitation of the forest. Areas where the entire stand is too heavily infected to permit carrying out sanitation measures without material interference with the silvicultural requirements of the forest should be marked for clear cutting. In practice such a condition will seldom be encountered. The largest possible number of small trees infected with mistletoe should be utilized. Areas of unmerchantable reproduction infected with mistletoe should be freed of the disease either through cutting the diseased seedlings and saplings or by pruning off infected branches. In certain cases it would be desirable for the owner of the forest to devote special funds for mistletoe-control projects, as is done in the case of serious insect infestations.

While the areas infected with mistletoe to such an extent that diseased trees must be left or the stand practically clear cut, are not extensive, areas will probably be found on which forest planting to fill in blank growing spaces will be desirable following operations approaching a clear cutting under a mistletoe-control project. It may also be advisable from the standpoint of economy to clear-cut and plant certain limited areas of heavy infection. A definite policy of mistletoe control should be adopted for mistletoe-infected areas to be cut over by timber sales. Necessary funds should be provided to complete the cleaning of the areas after the operator has removed all of the diseased trees which he can be required to take under the agreement.

Forests in the vicinity of nurseries and planting areas should present unusually healthy conditions. It should be remembered that healthy trees can not be grown in an insanitary environment. All mistletoe infection in the vicinity of forest nurseries and planting areas should therefore be removed.

When a proposed timber-sale area contains a considerable amount of mistletoe, a special mistletoe sanitation clause should be inserted in the contract, containing the stipulation that all heavily infected trees, whether merchantable or unmerchantable, and certain other moderately infected trees will be marked for cutting. If the amount of unmerchantable infected timber is sufficient to affect the stumpage price materially, this factor should be fully taken into consideration and due allowance made for it in the stumpage appraisal.

In control work on those areas where both mistletoe and insects are present, it would be advisable to combine the eradication of both pests where the commercial value of the stand justifies such measures. Infestations of secondary bark borers have occasionally been found and reported with or immediately following mistletoe infection.[14] It is believed that certain of these insects even show a slight preference for trees infected with mistletoe. The attack of trees weakened by the mistletoe often hastens their death, or in the case of dead trees the work of the borers hastens deterioration. The control of such combined infection and infestations by eliminating the weakened trees would tend to control both mistletoe and insects, and thus hasten the realization of the ideal—a productive, thrifty, and healthy forest.

The western yellow pine mistletoe probably has few natural enemies which can contribute toward its control. During the course of the studies reported in the preceding pages, a spittle insect (*Clastoptera obtusa*)[15] was very frequently found within masses of spittle on the mistletoe plants. The work of the insect in controlling the mistletoe is probably of little practical importance. However, since the insect subsists on the juices of the mistletoe, it must tend to weaken the mistletoe to a certain extent, especially in cases of severe infestations.

Through a proper realization and appreciation of the necessity for adequate control measures and their adoption on all cutting areas where the amount of mistletoe infection is relatively great, a very good beginning can be made toward the eradication of the pest through the more or less gradual process of elimination.

SUMMARY.

Western yellow pine is subject to severe injury by mistletoe (*Razoumofskya cryptopoda*). The injury to the forest caused by the insidious and destructive action of this pest results in serious losses of western yellow pine and presents one of the most important silvicultural problems in the Southwest.

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[14] Hopping, Ralph. Insect Infestation in Relation to Injury, Fungi, and Mistletoe. Manuscript report. February 24, 1915.

[15] Determined by E. H. Gibson, Scientific Assistant, Bureau of Entomology, U. S. Department of Agriculture.

Mistletoe infection causes a marked decrease in the rate of growth of the host, which continues until the virulent parasite ultimately causes the death of the tree. The rate of decrease varies directly with the degree of infection from little or no decrease in the growth of lightly infected trees to a very marked falling off in the current growth of heavily infected trees. Many trees are killed annually by this pest alone or in conjunction with other causes, such as insect infestations or porcupine injury.

The decrease in the rate of diameter and height growth and the consequent current increment of trees infected with mistletoe are accompanied by a reduction of the leaf surface of the host.

Trees of all age classes are subject to mistletoe infection, provided the seeds of the parasite fall on parts of the tree which are not protected by the bark. Young seedlings and saplings usually die comparatively soon after becoming severely infected, while older trees may remain alive for a much longer time.

The quantity and quality of the seed produced by trees infected with mistletoe is below that of normal, healthy trees. Heavily infected trees are practically worthless for seed production and should not be left as seed trees

The most practical method of controlling mistletoe is to remove the infected trees while cutting operations are in progress. All heavily infected trees should be marked for cutting. Moderately infected trees should be marked for cutting except where others are not available for seed trees. On areas of light to moderate infection the marking rules should require the removal of all mistletoe-infected trees possible without breaking up the continuity of the stand or materially interfering with the silvicultural requirements of the forest. Exceptional care should be taken to leave as heavy a stand of healthy trees as possible in order to compensate for the removal of diseased trees and to maintain better forest conditions.

Areas on which the entire stand is too heavily infected with mistletoe to permit adequate sanitation measures without very material interference with the silvicultural requirements of the forest should be marked for clear cutting under a mistletoe-control project. Although in actual practice such a condition will seldom be encountered, relatively small areas will probably be found on which forest planting may be desirable.

When proposed timber-sale areas contain a great amount of mistletoe, a sanitation clause should be inserted in the timber-sale contract requiring the cutting of all heavily infected trees, whether merchantable or unmerchantable, and certain other moderately infected trees which may be marked.

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DEVELOPMENT OF COOPERATIVE SHELTER-BELT DEMONSTRATIONS ON THE NORTHERN GREAT PLAINS.

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INTRODUCTION.

To show the possibility of planting trees for shelter belts and to demonstrate the proper methods of starting and caring for these plantings the Northern Great Plains Field Station near Mandan, N. Dak., in the development of one line of its work, has undertaken a cooperation with a number of farmers in the northern Great Plains area. The main objects of the cooperation are to stimulate interest in the improvement of farm homes by planting belts of trees around the farm buildings and to determine by actual trial the species of trees best adapted to the different sections of the region.

THE PLAN OF COOPERATION.

The United States Department of Agriculture undertakes under certain outlined conditions to furnish without charge to farmers living in the territory the trees necessary to plant a suitable shelter belt for the farm buildings. The farmer on his part agrees to plant and care for the trees in accordance with plans and instructions furnished by the department.

The working details of these cooperative shelter-belt demonstrations are issued in a series of five circulars which outline the methods

to be followed in preparing the land for tree planting, in planting the trees, and in cultivating and caring for the trees after planting. Special instructions are given for the planting and care of evergreen or coniferous trees.

Experience has shown that proper preparation of the land is essential to the successful growing of trees in these semiarid plains. The soil must be free from sod and growing grass and must contain at the time of planting a reasonable supply of moisture. Clean summer fallow has been found the most effective tillage method for this purpose. In addition to proper preparation of the land it is necessary to practice clean cultivation until such time as the trees are large enough to practically shade the entire space between the rows. Farmers are required to maintain these conditions as their part of the cooperation.

As the trees are grown under unusually severe conditions, nothing but small stock is used. The age and size of the different species are as follows: Box elder, Russian olive, and Tartarian maple, 1-year seedlings ranging from 6 to 24 inches high; green ash, caragana, and white elm, 2-year seedlings from 12 to 24 inches tall; and poplars, rooted cuttings. The caragana and poplars are cut back to about 8 inches to insure their proper growth after planting.

The conifers are of a necessity older stock, being seedlings transplanted to the field the second year and allowed to grow one or two years, according to the species—jack, Scotch, and western yellow pine are 2–1 transplants; that is, two years in the seed beds and one year in the transplant field. Spruce may be either 2–1, 2–2, or 2–3, according to the size of the original seedlings and the rate of growth made in the transplant fields.

The use of small stock insures a more satisfactory stand than when larger stock is used, besides insuring its delivery to the cooperating farmer in the best condition.

The farmers of this region having come into the northern Great Plains from other more favorable sections, are not familiar with the conditions under which trees may be grown. In addition to the printed instructions in regard to the work, all farmers are visited each summer to check up their work and to see if the plans and instructions have been followed. This has been found to be one of the most essential parts of the work, as without the personal visits and the assistance given by the field men, the farmer soon grows discouraged and often abandons the trees to grow as they may, which results in their failure, due to the growing about them of grass and weeds. The farmer is also furnished cards on which to report the cultivations during the summer and the losses during the first two summers.

AREA COVERED BY SHELTER-BELT DEMONSTRATIONS.

The area covered by this work comprises the western half of the States of North Dakota, South Dakota, and that part of Montana and Wyoming lying east of the Rocky Mountains. The region is roughly 500 miles square and contains a wide variation in topography, soil, and climate. The area is shown inclosed by a heavy line in Figure 1.

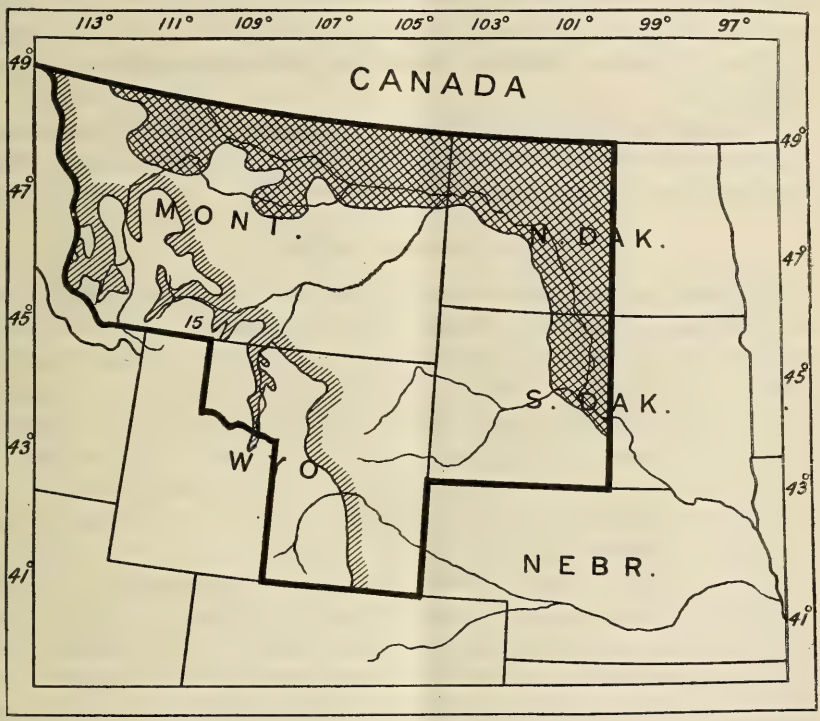

FIG. 1.—Map of the northern Great Plains, showing within the heavy line the area to which the cooperative shelter-belt demonstrations are restricted. The glaciated section of the area is indicated by the crosshatched portion along its northern and eastern sides.

TOPOGRAPHY.[1]

GLACIATED SECTION.

The glaciers at different times extended across the Missouri River for distances ranging from a few miles to 40 or 50 miles. This

[1] Descriptions of the surface features of this region are taken in part from the following publications:

Calhoun, Fred. H. H. The Montana lobe of the Keewatin ice sheet. U. S. Geol. Surv. Prof. Paper 50 (ser. B. Desc. Geol. 79), 62 p., 30 fig., 7 pl. (partly col.), 1906.

Lapham, Macy H., et al. Soil survey of western North Dakota. U. S. Dept. Agr., Bur. Soils, Field Operations—Advance Sheets, 1908, 80 p., 1 fig., 6 pl., 1 col. map, 1910.

Leonard, Arthur Gray. The surface features of North Dakota and their origin. In Quart. Jour., Univ. N. Dak., v. 9, no. 3, April, 1919.

Wright, G. Frederick. The Ice Age in North America and Its Bearing upon the Antiquity of Man, xviii, 648 p., 148 fig., 1 pl., 3 maps. New York and London, 1891.

glaciated area is for the most part an undulating prairie, except for a belt of rough morainic hills called the "Coteau du Missouri." This belt of hills, which marks the limit of the Wisconsin ice sheet, extends diagonally across the State of North Dakota, conforming in general to the course of the Missouri River, but at a distance of some 50 miles more or less to the north and east. It varies from 10 to 20 miles in width and rises in massive hills and ridges strewn with granite bowlders to heights of 150 to 200 feet above the surrounding prairie. Numerous hollows and undrained depressions between these hills and ridges are occupied by swamps and alkaline and fresh-water lakes.

Practically all the glaciated area in Montana is rolling prairie or level stretches of bench land, all of which is well drained. The glaciated area is indicated in Figure 1.

NONGLACIATED SECTION.

The remainder of the region lying between the Missouri River and the foothills of the Rocky Mountains is untouched by the action of the glaciers, and the surface features are almost wholly the result of erosion. It is an area of rolling and for the most part treeless prairies or broad sweeping valleys. The entire section is drained by the Yellowstone and Missouri River systems. So complete a system of watercourses is formed by the tributaries of these rivers that practically the entire surface takes the form of slopes leading into some drainage basin.

Several isolated groups of small mountains rise abruptly from the prairie at a considerable distance from the frontal range of the Rocky Mountains. They are the Black Hills in South Dakota; the Highwood Mountains, the Bearpaw Mountains, the Sweet Grass Hills, and the Larb Hills in Montana. These groups are described by the United States Geological Survey as, for the most part, igneous intrusions and not connected directly with the Rocky Mountains. With the exception of the Larb Hills, they are all covered with a more or less heavy stand of coniferous trees. The heavy growth of western yellow pine that once covered the Bearpaw Mountains now shows the marked effect of thinning through the combined work of settlers and fire.

Another feature of this nonglaciated section is the large number of conical or flat-topped buttes rising several hundred feet above the general level and forming prominent landmarks that can be seen for great distances. These buttes were formed by the erosion of the surrounding soil and are remnants of the ancient Missouri Plateau that once covered the entire section. Notable examples of this formation are the Killdeer and Turtle Mountains in North Dakota, the

Cave Hills and Slim Buttes in South Dakota, and the Pine Hills in southeastern Montana.

SOILS.

There is great diversity in the types of soil that characterize the northern Great Plains region. These soils range from sand and sandy loam through silt and clay loam to heavy clay and shale. In general there is a large proportion of clay in the subsoil, giving it a high water-holding capacity. In certain sections small areas of hardpan are found which the roots of the trees seem unable to penetrate. Cultivation of this type of clay soil is ineffective in making these areas suitable for tree growth. Another small proportion presents a deep gravel subsoil on which trees do not thrive. There are also occasional spots where the percentage of alkaline salts is high enough to stunt or kill out a planting of trees.

A fairly extensive sand-dune area is found in the northeastern corner of the region, in and southeast of the valley of the Mouse River in North Dakota. Here the water table is quite near the surface, and such trees as willow and aspen are found growing naturally in slight depressions that occur in the prairie. Groves of trees planted on timber claims in this area have maintained themselves and made excellent growth.

CLIMATE.

The northern Great Plains are in what is known as the dry-land farming area of the United States. The climate has been classified as semiarid. It may be more accurately described as variable, changing from season to season from almost humid conditions to almost arid, but with a relatively low average annual precipitation ranging from 10 to 20 inches. Another uncertain factor is the seasonal distribution of the rainfall. It is possible for a comparatively low rainfall favorably distributed to produce normal plant growth, while a much higher rainfall unfavorably distributed may result in damage to a plantation through lack of moisture at some critical period of the growing season. Very high summer temperature and very low winter temperature, coupled with frequent strong winds throughout the entire year, combine to make this one of the most severe regions for tree growth in the United States.

Table 1 gives the highest, lowest, and average seasonal and annual precipitation at 10 field stations of the Bureau of Plant Industry in the area for the 5-year period from 1916 to 1920, inclusive. It also gives the average seasonal evaporation for the same years. Most of these stations have United States Weather Bureau records of precipitation covering a period of 15 to 45 years. The average precipitation for the entire period of the record is given in the table.

TABLE 1.—*Precipitation and seasonal evaporation at 10 field stations in the northern Great Plains for the 5-year period from 1916 to 1920, inclusive.*

Station.	Altitude (feet).	Precipitation (inches).							Evaporation, seasonal[1] (inches).
		Seasonal.[1]			Annual.			Normal annual.[2]	
		Maximum.	Minimum.	Average.	Maximum.	Minimum.	Average.		
Mandan, N. Dak	1,750	11.38	9.22	10.15	15.07	10.31	12.96	17.05	35.460
Dickinson, N. Dak	2,543	13.89	5.82	10.18	18.21	8.35	12.81	15.77	34.158
Hettinger, N. Dak	2,253	13.18	6.39	10.11	15.91	7.85	12.74	14.96	32.762
Newell, S. Dak	2,950	20.56	8.44	12.78	25.89	13.32	17.03	15.20	34.174
Ardmore, S. Dak	3,557	17.53	10.57	13.29	20.26	13.53	16.66	17.55	37.274
Havre, Mont	2,505	14.88	4.85	8.57	19.24	7.56	11.68	13.67	35.727
Moccasin, Mont	4,200	15.63	4.77	10.74	19.87	9.90	16.44	16.61	35.335
Huntley, Mont	3,037	9.87	5.31	7.88	15.14	12.22	13.62	13.84	34.256
Sheridan, Wyo.[3]	3,790	12.41	5.28	8.60	17.38	8.56	13.52	14.72	35.525
Archer Wyo	6,017	15.59	8.53	11.62	19.09	12.39	14.79	13.60	36.845

[1] Seasonal precipitation and evaporation are for the 6-month period from Apr. 1 to Sept. 30, inclusive.
[2] Mean annual precipitation is the average of the entire record.
[3] Sheridan data, except mean annual precipitation, are for the four years from 1917 to 1920, inclusive.

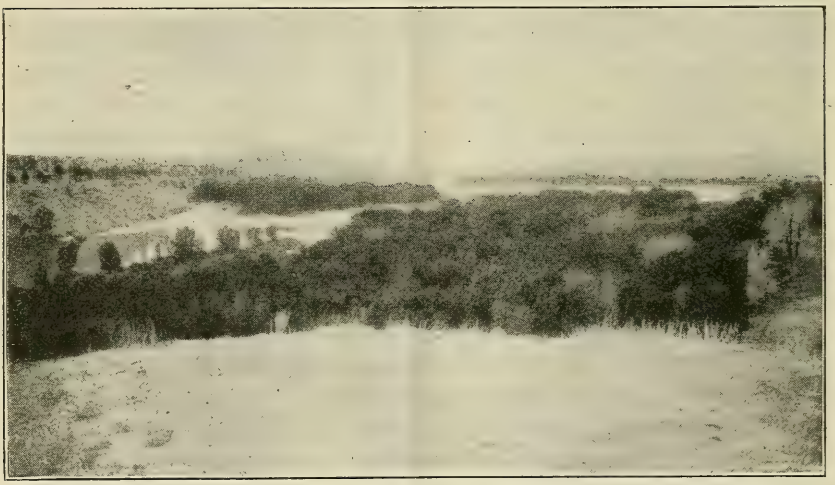

FIG. 2.—The Yellowstone River valley at Pompeys Pillar in southern Montana, showing native growth of western cottonwood, box elder, and green ash in the river bottom and yellow pine on the adjoining hills.

NOTES ON TREE SPECIES.

In determining the adaptability of any tree species for planting on the open prairie of this region, its ability to resist drought and extreme cold is a factor of prime importance. In this area of limited moisture, late spring frosts, and early autumn frosts it is found that many of the species adapted to shelter-belt use have a comparatively short growing season. Their leaves are not put out until spring is well advanced and terminal buds are generally set in late summer. It naturally follows that the native tree growth found along the rivers and in the coulees and on certain groups of hills throughout

the region furnishes what is perhaps the most important source of material for shelter-belt planting.

Figure 2 shows the native growth of western cottonwood, box elder, and green ash in the river bottom, with western yellow pine on the adjoining hills in the Yellowstone River valley at Pompeys Pillar in southern Montana.

Figure 3 is a view in the Turtle Mountains, Bottineau County, N. Dak., showing the native tree growth, consisting of cottonwood, balsam poplar, aspen, white elm, bur oak, and green ash.

The species that make up this native growth are of two general classes: Those which have progressed up the Mississippi-Missouri River system from the east and those which have advanced down the western sources of this same system from the Rocky Mountains.

FIG. 3.—View in the Turtle Mountains, Bottineau County, N. Dak., showing native tree growth consisting of cottonwood, balsam, poplar, aspen, white elm, bur oak, and green ash.

Beside these native trees a number of species have been introduced from other parts of the United States and Canada and from certain European and Asiatic countries. Some of these introduced species are fully as adaptable to shelter-belt use as any of the native species, while a number of the native trees can not be successfully transplanted to the open plains.

The following paragraphs give brief descriptions of practically all of the trees which have been used in shelter-belt planting in the northern Great Plains region. The list is not exhaustive, however, as there are a number of other species that can doubtless be made to grow, but about which little data are available at the present time.

DECIDUOUS OR HARDWOOD SPECIES NATIVE TO THE REGION.

Box elder.—The box elder (*Acer negundo*) is found in practically all of the river valleys to the foothills of the Rocky Mountains.

It is rarely found growing very far from the moist bottom lands and does not push its way up the dry coulees toward the prairie levels. It is, however, a very useful tree for prairie planting, adapting itself readily to upland conditions, and has been known to persist in sod for a number of years after attaining reasonable size under cultivation. It may be classed as one of the best for shelter-belt planting in all types of soil throughout the entire region.

Green ash.—The green ash (*Fraxinus lanceolata*) is found in much the same range as the box elder. It prefers somewhat drier sites and often works its way up the long open coulees to the level of the prairie. In these situations it is frequently mixed with white elm, June berry, wild plum, buffalo berry, and chokecherry. It ranks with the box elder as one of the best trees for shelter-belt planting, doing well on all types of soil except sand and gravel, and it shows a marked ability to live through periods of extended drought.

White elm.—The white elm (*Ulmus americana*) though generally considered a moisture-loving tree, is found in company with the green ash and buffalo berry in such comparatively dry situations as open valleys far removed from running water. Here it maintains itself in sod on the sides of dry runs. This occurs more generally at the western limit of its range, which is in eastern Montana and the Black Hills of South Dakota. In the Plains region it departs somewhat from its usual graceful shape, old trees at a distance resembling gnarled oaks. It is a good tree in shelter-belt plantings, showing a preference for clay soils. It is difficult to get seed for propagation, as the blossoms are often injured by the late spring frosts.

Western cottonwood.—The western cottonwood (*Populus deltoides* var. *occidentalis*) is the dominant tree species along the larger river valleys of the Great Plains where it often attains great age, forming extensive open groves. It grows at some distance from its usual bottom-land habitat and may occasionally be found far up some dry run. It is a very good tree in shelter-belt planting throughout the area east of the Missouri River; farther west, however, it does not succeed as well. It adapts itself to either sand or clay soils, but is not to be recommended for dry situations.

Balsam poplar.—The balsam poplar (*Populus balsamifera*) is found in the Black Hills in South Dakota; the Turtle Mountains, the Mouse River Valley, and on lake shores in the Coteau du Missouri in North Dakota; and possibly in the Little Rocky Mountains and the Sweet Grass Hills in Montana. The tree has not been planted for shelter-belt purposes except in a limited area south of the Turtle Mountains in North Dakota. As it is essentially a

northern tree, ranging nearly to the Arctic Circle, it may not adapt itself to the hot summer temperatures of the Great Plains.

Aspen.—The aspen (*Populus tremuloides*) is scattered sparsely over portions of the Plains region. It is found in the river valleys, on the north sides of small mountain groups, on occasional steep bluffs, and in the sand-dune area near the Mouse River in North Dakota. It is also found on the borders of lakes in the Coteau du Missouri and in depressions or coulees in the prairie where underground springs exist. It has been used in some instances for farm plantings, and makes a dense growth, though of no great size.

Northwest poplar.—The northwest poplar (*Populus* sp.) was given its name by one of the commercial nurseries in North Dakota. It was discovered in the northern part of that State, and is supposed

FIG. 4.—Northwest poplar (row at left) in its fourth year of growth in a shelter belt in Sheridan County, N. Dak.

to be a natural hybrid presumably between the balsam poplar and the aspen. Whatever its origin, it is the most promising poplar for shelter-belt planting in the Great Plains area that has yet been tested. It is perfectly hardy, seems to grow on all types of soil, and is superior to the cottonwood on the drier locations. Figure 4 shows the northwest poplar in its fourth year of growth in a shelter belt in Sheridan County, N. Dak.

Acute-leaved cottonwood.—The acute-leaved cottonwood (*Populus acuminata*) is native to the foothills of the Rocky Mountains. It is found along the banks of streams in Montana as far east as the Powder River and in Wyoming to the Black Hills in South Dakota. This tree has been used for street planting in cities of the Rocky Mountain region, and is superior for that purpose to the common

cottonwood (*P. deltoides*). It has not yet been tested throughout the Great Plains region as a shelter-belt tree.

Narrow-leaved cottonwood.—The narrow-leaved cottonwood (*Populus angustifolia*) prefers moister situations than its related species, and clings closely to the river and creek margins and low flood lands. It is a Rocky Mountain species, having a range much more restricted than the acute-leaved poplar. It has been planted as a street tree within its range, but it makes a poor showing for this purpose. Its usefulness for shelter-belt planting is doubtful.

Diamond willow.—The diamond willow (*Salix mackenzieana*) is found generally throughout the Great Plains area. It follows the river and creek bottoms to the foothills of the Rocky Mountains. It is a tree of some economic importance as a source of fence posts. It has been planted in shelter belts on the prairie with only fair success.

Bur oak.—The bur oak (*Quercus macrocarpa*) is found as far west as the Black Hills and in the Bad Lands of western North Dakota, southeastern Montana, and northeastern Wyoming. It grows on the drier sites along stream banks and old flood plains, occasionally venturing to the lower prairie levels. It does not grow to a great size, though specimens are found of apparent great age. It has not been considered a practical tree for transplanting to shelter-belt sites.

Chokecherry.—The chokecherry (*Prunus virginiana*) ranges throughout the entire Great Plains region along the river courses and up the dry coulees to the prairie levels, where it is often found associated with the green ash. It is well adapted for shelter-belt planting, doing well in all situations except very sandy or low wet soils.

Buffalo berry.—The buffalo berry, or bullberry (*Shepherdia argentea*), is closely associated with the chokecherry in range and adaptability for shelter-belt planting. It is more suited to the sandy types of soil, but does not favor low wet situations.

CONIFEROUS OR EVERGREEN SPECIES NATIVE TO THE REGION.

Black Hills spruce.—The Black Hills spruce (*Picea canadensis*), a form of white spruce found in the Black Hills of South Dakota, has certain characteristics which distinguish it from the common white spruce of northern Minnesota and Canada. It is not exacting as to soil types, but prefers the drier locations. It is one of the best evergreens for shelter-belt planting in the northern Great Plains.

Figure 5 shows spruce on the east side of the deciduous shelter belt at the Northern Great Plains Field Station, Mandan, N. Dak. The three rows from left to right are blue spruce, white spruce, and Black Hills spruce. The relatively greater size of the Black Hills spruce

is partly due to its being the outside row, farthest from the deciduous trees.

Western yellow pine.—The western yellow pine, or bull pine (*Pinus ponderosa*), is found extensively over the western portion of the northern Great Plains area on the hills and rocky outcrops from the Little Missouri River and the Black Hills to the Rocky Mountains. It is an extremely hardy tree in its natural habitat, but as yet has not been transplanted to prairie situations with much success. It is probably suited to special localities, but present data do not recommend it for general use.

Lodgepole pine.—The lodgepole pine (*Pinus murrayana*) is found at low altitudes in the Rocky Mountains and in the outlying groups

FIG. 5.—Spruce in a planting at the Northern Great Plains Field Station, Mandan, N. Dak. The row on the left center is blue spruce, the center row is white spruce, and the one at the right is Black Hills spruce.

of small mountains in the Great Plains region where it is confined principally to the northern slopes. It has proved adaptable for shelter-belt planting in Alberta and Saskatchewan, Canada, but has not yet been tested in the United States.

Douglas fir.—The Douglas fir (*Pseudotsuga taxifolia*) extends east from the Rocky Mountains in company with western yellow pine to central Montana. It is found in the coulees, or "breaks," along the Missouri River up to the very edge of the prairie. It may be classed with the western yellow pine in adaptability for shelter-belt planting.

Red cedar.—The red cedar, or juniper (*Juniperus virginiana*), grows as a low, shrubby tree among the rough hills overlooking the river valleys of the region. It is extremely hardy and makes good growth when transplanted. It has not been used, however, for shelter-belt planting to any extent.

DECIDUOUS OR HARDWOOD SPECIES INTRODUCED TO THE REGION.

Carolina poplar.—The Carolina poplar (*Populus* sp.) is propagated by commercial nurseries and has been widely used in past years for shelter-belt planting on the prairies east of the northern Great Plains region. It is probably a selection of the common cottonwood taken in the central or eastern United States. Extensive tests with this variety in shelter belts on the northern Great Plains have proved it entirely unsuited for general planting in this region.

Norway poplar.—The Norway poplar (*Populus* sp.) is propagated extensively by commercial nurseries. It closely resembles the Carolina poplar. Extensive tests in shelter-belt plantings in the northern Great Plains indicate that it is unsuited for general planting in this section.

Canadian poplar.—The Canadian poplar (*Populus* sp.) is one of several varieties imported a number of years ago from northern

FIG. 6.—Shelter-belt planting of box elder, northwest poplar, and green ash planted 6 by 6 feet at Archer, Mont., showing clean cultivation in the first year of growth.

Russia or Siberia and propagated by commercial nurseries in the United States and Canada. This variety has been extensively planted in the Plains region of Canada, where it has proved quite adaptable for shelter-belt use. Plantings in the Plains region of the United States, however, have shown that it is subject to attack by canker, which kills the trees in three or four years. This disease makes it a questionable variety for general use in this region.

Laurel-leaf willow.—The laurel-leaf willow (*Salix pentandra*) is extensively propagated by commercial nurseries for shelter-belt planting in the Northwest. It was imported a number of years ago from Europe. While it is reasonably hardy, it does not seem able to establish itself in the upland prairie locations on the Great Plains. Extensive test plantings have grown nicely for one or two years and then killed out for what seems to be lack of sufficient moisture.

It can not be recommended for general planting in this section. It seems, however, to be well adapted for planting on the prairies in the eastern part of the Dakotas and in western Minnesota.

Russian golden willow.—The Russian golden willow (*Salix vitellina*), like the laurel-leaf willow, has been extensively propagated by commercial nurseries for planting in the Northwest. It was imported a number of years ago from Russia. It has been extensively tested throughout the Great Plains area and has killed out over large areas after one or two years, the same as the laurel-leaf willow. It can not be recommended for general planting in this section, but it seems to do well on the prairies farther east.

Honey locust.—The honey locust (*Gleditsia triacanthos*) is native to southern Minnesota and South Dakota. It is hardy in a few isolated sections of the northern Great Plains, but can not be recommended for general planting.

FIG. 7.—A 5-year old planting of box elder, green ash, and white elm in Ziebach County, S. Dak. This illustration shows the trees filling the spaces between the rows which are 8 feet apart.

Caragana.—The caragana, or Siberian pea tree (*Caragana arborescens*), is an importation of some years back from Siberia. It is especially hardy and drought resistant and is one of the best trees for general shelter-belt planting in the northern Great Plains. It is adapted to all types of soil except sand or gravel, but does not thrive in low, wet situations.

Russian olive.—The Russian olive (*Elaeagnus angustifolia*) is an importation made some years ago from northern Russia. Like the caragana, it is especially hardy and drought resistant and may be classed with it as a valuable tree for shelter-belt planting in the northern Great Plains area. It adapts itself to all types of soil, but does not thrive in low, wet situations.

Chinese elm.—The Chinese elm (*Ulmus pumila*) was introduced several years ago from northern China. It has not proved entirely hardy in the northern portion of this region, where a tendency is

shown to winterkilling and drying out for lack of moisture. In certain sections it has made an excellent growth, but it can not yet be recommended for general use.

CONIFEROUS OR EVERGREEN SPECIES INTRODUCED TO THE REGION.

Scotch pine.—The Scotch pine (*Pinus sylvestris*) is a native of northern Europe and Asia and has been widely planted in the United States. It grows successfully on the prairies east of the Great Plains region, and recent plantings within the region indicate that it is one of the best evergreens for shelter-belt use. It is not as well adapted to sand and gravel soil as the jack pine and does not do well in moist or low, wet situations.

Jack pine.—The jack pine (*Pinus divaricata*) is found extensively on the more sandy soils of northern Minnesota. It is adapted to shelter-belt planting on the Great Plains, especially on sandy soil.

FIG. 8.—A shelter belt near Isabel, S. Dak. In the foreground are Scotch pines planted in 1920 and jack pines planted in 1921 in east and west rows on the south side of the broadleaf section planted in 1916. Photographed in July, 1921.

It does not do well on clay soil and should not be placed in moist or low, wet situations.

White spruce.—The white spruce (*Picea canadensis*) has a wide range in northern Minnesota and Canada. It is adapted to shelter-belt planting on the Great Plains and is suitable for practically all types of soil. It will grow in either wet or dry situations.

Blue spruce.—The blue spruce, or Colorado blue spruce (*Picea parryana*), is native to the Rocky Mountains of Colorado, Utah, and Wyoming. It appears to be perfectly hardy when planted in shelter belts in the northern Great Plains. It is more exacting as to soil requirements than the white spruce, showing preference for clay soils.

TREES IN RELATION TO SOIL TYPES.

Not all species of trees adapted to this region grow equally well on the same type of soil. The typical shelter-belt planting site is on the open upland prairie where the soil texture falls into the general

classifications of clay or silt loam, sandy loam, and sand or gravel and the moisture supply is derived entirely from the rainfall. Exceptional planting sites are found where lack of drainage or nearness to streams and water tables affords a moist or low, wet soil condition. Table 2 lists the several tree species according to their adaptability to the above rough classification.

TABLE 2.—*Adaptation of tree species to the several soil types or conditions on the Northern Great Plains.*

Clay or silt loam.	Sandy loam.	Sand or gravel.	Moist soils.	Low wet soils.
Box elder	Box elder	Box elder	Box elder	Box elder.
Northwest poplar	Northwest poplar	Northwest poplar	Northwest poplar	Northwest poplar.
Green ash	Green ash		Green ash	Green ash.
White elm			White elm	White elm.
Caragana	Caragana		Caragana	
Buffalo berry	Buffalo berry	Buffalo berry	Buffalo berry	
Russian olive	Russian olive	Russian olive	Russian olive	
Chokecherry	Chokecherry		Chokecherry	
			Cottonwood	Cottonwood.
White spruce	White spruce	White spruce	White spruce	White spruce.
Black Hills spruce	Black Hills spruce	Black Hills spruce	Black Hills spruce	
Blue spruce	Blue spruce		Blue spruce	
Scotch pine	Scotch pine			
	Jack pine	Jack pine		
			Willow [1]	Willow.[1]

[1] Laurel-leaf Russian golden, or diamond willow.

FIG. 9.—A shelter belt planted in 1916 that is an effective factor in the development of a home on the treeless plains at Fowler, Mont. Photographed in 1921.

SHELTER-BELT PLANTING PLANS.

The demonstration shelter belts are laid out in long belts ranging from 5 to 10 or more rows spaced 8 feet apart. In most of the plantings the trees have been placed 4 feet apart in the row. Recent observations made of the plantings set out in 1916 indicate that a wider spacing might be better, especially for the average site, in order that the individual trees may reach a larger size be-

fore competition with the adjacent trees for the soil moisture begins. There is a generally accepted belief that close spacing is desirable in order that the trees may quickly grow together and shade the ground, thus keeping out the grass and weeds. Careful cultivation must be practiced until this result is attained. Wider spacing of trees naturally lengthens the period during which cultivation is necessary. The guiding principle for spacing, therefore, is to plant the trees as close together as possible without forcing them to compete with each other for moisture at too early an age. It seems probable that 6 by 8, 8 by 8, or 6 by 10 feet apart are preferable to closer distances in this section.

Figure 6 shows clean cultivation in the first year of a planting spaced 6 by 6 feet at Archer, Mont. The light-colored row is northwest poplar.

FIG. 10.—A planting made in 1917 at Dupree, S. Dak. The trees have had clean cultivation and made good growth. Photographed in 1921.

Figure 7 shows a planting of box elder, green ash, and white elm in Ziebach County, S. Dak. The rows in this planting were 8 feet apart. The photograph, taken in the fifth year of growth, shows that the trees have met and fill the spaces between the rows.

The selection of species and their arrangement are made with the view of establishing a dense shade that will exclude the sunlight both from above and on the sides. Outside rows are planted to low-growing species, such as caragana, Russian olive, chokecherry, and buffalo berry. The interior of the belt is planted to alternating rows of box elder and green ash, green ash and white elm, box elder and poplar, or a combination of all these species.

The ideal tree for shelter is the conifer, or evergreen. It is found, however, that in this region it is necessary to provide some kind of shelter for them when they are first planted. A plan has been

adopted of setting out a shelter belt of deciduous species as described above and later adding evergreens along the sheltered edge or inside of the original planting. Care must be taken to leave a space of some 20 feet between the two plantings, or the small evergreens may suffer from competition with the roots of the older planting for moisture.

Figure 8 shows Scotch pine planted in 1920 and jack pine planted in 1921 in east and west rows on the south side of the hardwood shelter belt planted in 1916. This planting is near Isabel, S. Dak. The photograph was taken in July, 1921.

FIG. 11.—Box elder and green ash planted in 1918 in western North Dakota and abandoned to weeds after being cultivated two years. Trees can not compete in this section with annual weeds or perennial grass.

DEMONSTRATION PLANTINGS.

All of the planting stock used in these shelter-belt demonstrations, except the Chinese elm, was grown either from seed or cuttings or as transplants in the nursery at the Northern Great Plains Field Station. Tables 3 to 6, inclusive, give the number and kind of trees sent out for planting in each of the four States in the territory covered by this work, during the 5-year period from 1916 to 1920, inclusive.

The shipments of each kind of stock to cooperators in each State in 1916 are shown in Table 3. Shipments of planting stock totaled 701,911. A little over half of this number consisted of willow and poplar cuttings which were made up of approximately equal numbers of laurel-leaf willow, Russian golden willow, Norway poplar, and Carolina poplar. The summer season of 1916 was one of very favor-

able moisture conditions, and a large percentage of these cuttings took root and made good growth. In northern Montana an early frost occurring in August caused some damage. During the winter of 1916–17 nearly all the trees were injured by freezing to some extent, but none as severely as the willow and poplar.

Details of the 1917 shipments, which totaled 357,700, are also given in Table 3. White elm was used for the first time this year and, although the summer was very dry, made an excellent growth. The Norway and Carolina poplars proved so unsatisfactory in both 1916 and 1917 that their use was discontinued. Cuttings of both willow and poplar were almost a complete failure under the dry conditions that prevailed, and the further use of cuttings for demonstration plantings was discontinued.

TABLE 3.—*Number of trees of each species or kind of stock shipped to cooperators in each State in 1916 and 1917.*

Season and State.	Species or kind of stock.								Total.
	Willow (cuttings).	Willow (rooted).	Poplar (cuttings).	Poplar (rooted).	Box elder.	Green ash.	Caragana.	White elm.	
Season of 1916:									
Montana	126,506	10,283	120,983	15,291	140,550	3,964	33,977	.....	451,554
North Dakota	30,408	4,139	28,279	5,562	37,159	12,969	13,287	.....	131,803
South Dakota	23,708	1,233	26,580	1,157	25,519	100	5,626	.....	83,923
Wyoming	9,504	294	9,243	2,073	10,185	.....	3,332	.....	34,631
Total	190,126	15,949	185,085	24,083	213,413	17,033	56,222	.....	701,911
Season of 1917:									
Montana	6,211	65,002	.....	16,114	39,798	69,600	2,163	27,982	226,870
North Dakota	2,512	20,507	.....	4,244	14,995	30,473	922	10,906	84,559
South Dakota	638	8,703	.....	2,044	6,771	9,338	283	4,154	31,931
Wyoming	.....	4,379	.....	2,748	3,667	2,412	505	629	14,340
Total	9,361	98,591	.....	25,150	65,231	111,823	3,873	43,671	357,700

Figure 9 shows one of the 1916 plantings, made near Fowler, Mont., that is becoming an effective unit in the development of a farm home on the Plains.

Figure 10 is reproduced from a photograph taken in 1921 of one of the 1917 plantings at Dupree, S. Dak. The trees have had clean cultivation and made good growth. After one or two more seasons' growth the trees will meet between the rows and cultivation cease.

Figure 11 shows one of the plantings made in 1918 in western North Dakota that was abandoned to weeds after two years of cultivation. Trees on upland in this section can not compete with perennial grasses and annual weeds.

Shipments in 1918 totaled only 142,302. The number of each species sent to each State is shown in Table 4. The marked reduction in the amount of planting stock sent out was due to the severe drought of 1917, which caused great loss to the trees grown at the station nursery.

The season of 1918 was one of deficient rainfall over practically the entire area. The willows were most affected by the successive dry conditions of 1917 and 1918. Those planted in 1916 and 1917 showed extensive winter injury.

TABLE 4.—*Number of trees of each species or kind of stock shipped to cooperators in each State in 1918 and 1919.*

Season and State.	Species or kind of stock.								Total.
	Willow (rooted).	Box elder.	Green ash.	Caragana.	Chinese elm.	Scotch pine.	Western yellow pine.	Jack pine.	
Season of 1918:									
Montana	22,242	14,843	24,424	20,617	2,390	.....	.....	.....	84,516
North Dakota	7,142	4,993	8,456	9,607	490	.....	.....	.....	30,688
South Dakota	5,952	3,984	7,707	2,397	200	.....	.....	.....	20,240
Wyoming	1,880	1,139	1,947	1,772	120	.....	.....	.....	6,858
Total	37,216	24,959	42,534	34,393	3,200	.....	.....	.....	142,302
Season of 1919:									
Montana	40,041	2,228	27,371	4,355	211	2,075	1,775	1,850	79,906
North Dakota	30,645	9,650	18,490	1,596	15	750	500	500	62,146
South Dakota	7,629	223	5,322	226	26	1,375	550	1,300	16,651
Wyoming	1,948	102	1,004	55	.....	250	250	250	3,859
Total	80,263	12,203	52,187	6,232	252	4,450	3,075	3,900	162,562

A shipment of Chinese elm was received from the Office of Foreign Seed and Plant Introduction of the United States Department of Agriculture for trial in this section. These trees were sent to 20 selected farmers and made good growth in all cases.

Details of the distribution of 162,562 trees shipped to cooperators in 1919 are also given in Table 4.

TABLE 5.—*Number of trees of each species or kind of stock shipped to cooperators in each State in 1920.*

State.	Species or kind of stock.									Total.
	Northwest poplar.	Box elder.	Green ash.	Buffalo berry.	Tartarian maple.	Scotch pine.	Western yellow pine.	Jack pine.	Blue spruce.	
Montana	2,506	28,262	17,259	608	1,371	9,405	4,821	1,946	1,285	67,463
North Dakota	.....	13,766	9,223	.....	.....	472	1,645	3,690	468	29,264
South Dakota	600	9,685	4,669	135	40	3,635	549	706	52	20,071
Wyoming	.....	3,863	1,561	.....	.....	399	249	1,313	.....	7,385
Total	3,106	55,576	32,712	743	1,411	13,911	7,264	7,655	1,805	124,183

The drought continued in 1919, making the third successive year of dry conditions. Except in especially favorable locations the willow was rapidly dying out over the entire area and its further use was discontinued. The small number of Chinese elm listed was used in making replacement to the plantings made in 1918, which in most instances came through the winter in fine condition and made excellent growth during the summer. Coniferous trees obtained from

the Forest Service nursery, Halsey, Nebr., and grown for one year at Mandan, N. Dak., were sent out to 23 selected farmers. These plantings were almost total failures on account of the very dry soil condition at the time they were set out.

In 1920, shipments to cooperators totaled 124,183 trees. The distribution of the shipments by species and States is given in Table 5.

The year 1920 was one of drought over nearly the entire territory, making the fourth year in succession in which the rainfall was below normal. Tartarian maple and buffalo berry were used

TABLE 6.—*Summary of Tables 3 to 5, inclusive, showing the total number of trees of all species shipped to cooperators in each State for each year of the 5-year period from 1916 to 1920, inclusive.*

State.	1916	1917	1918	1919	1920	Total.
Montana	451,554	226,870	84,516	79,906	67,463	910,309
North Dakota	131,803	84,559	30,688	62,146	29,264	338,460
South Dakota	83,923	31,931	20,240	16,651	20,071	172,816
Wyoming	34,631	14,340	6,858	3,859	7,385	67,073
Total	701,911	357,700	142,302	162,566	124,183	1,488,658

for the first time in a few places. Coniferous plantings were again almost total failures, on account of dry soil conditions. It is probable that this type of tree can only be established in years of favorable rainfall.

Northwest poplar, which had grown successfully in test plantings at Mandan for four years, was sent out for the first time to a few selected cooperators.

TABLE 7.—*Number of cooperative shelter belts planted each year, the number of each year's plantings listed as successful or as having failed on January 1, 1921, and the percentage of failures.*

Year.	Number planted.	Number successful on Jan. 1, 1921.	Number that had failed by Jan. 1, 1921.	Percentage of failures.
1916	633	319	314	49.6
1917	232	117	115	49.5
1918	75	37	38	50.6
1919	202	154	48	23.7
1920	92	89	3	3.3
Total	1,234	716	518	42.0

In Table 6 the shipments of trees to cooperators during the 5-year period from 1916 to 1920, inclusive, are summarized to show the number shipped to each State each year, the total shipments each year, and the total number sent to each State in the five years. In the five years, 910,309 trees were shipped to Montana, 338,460 to North Dakota, 172,816 to South Dakota, and 67,073 to Wyoming. The total number of trees in shipments to the four States in the five years was 1,488,658.

Table 7 shows the number of shelter belts planted by cooperators with trees furnished by the Northern Great Plains Field Station during the 5-year period from 1916 to 1920, inclusive. It also shows the number of the plantings made each year that were listed as successful on January 1, 1921, the number listed on that date as having failed, and the percentage of failures. In the five years 1,234 plantings were made and at the end of the period 716, or 58 per cent, of these were listed as successful and 518, or 42 per cent, as having failed. Almost exactly 50 per cent of the plantings made in each of the years 1916, 1917, and 1918 were listed as successful at the end of the 1920 growing season.

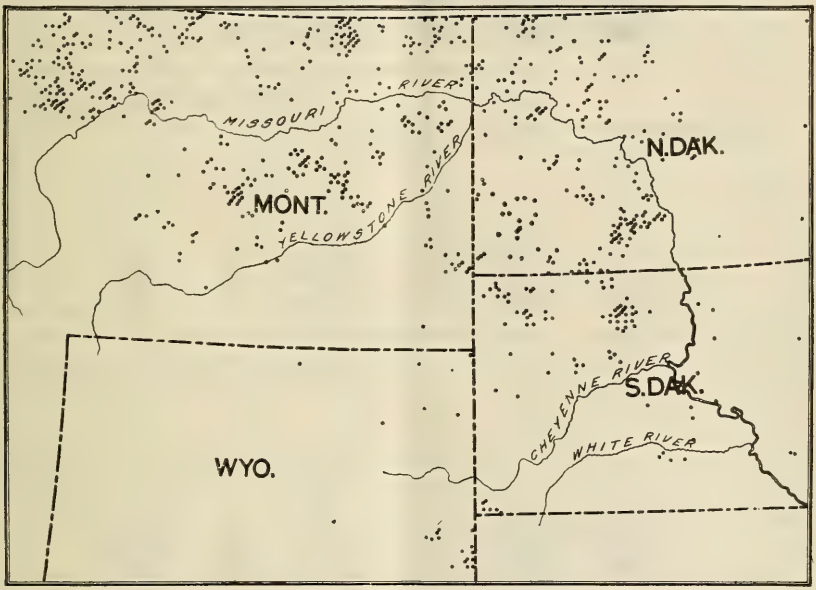

FIG. 12.—Outline map of the Northern Great Plains region. Each township in which one or more plantings of shelter belts had been made in 1917 or in which application had been made for planting in 1918 is indicated by a dot.

Failures may be and were due to any one or more of several causes. The more frequent causes have been improper planting, lack of care and cultivation, prolonged drought, and the owner leaving the farm. The years from 1917 to 1920, inclusive, were all years of severe drought over the greater part of the territory covered by the shelter-belt work. Such a succession of drought years is unprecedented in the time for which records are available. The work has consequently been in progress during the most unfavorable years it is likely to experience. Continued drought leads to economic stress which is reflected on such projects as this either by abandonment of the farm or inability to properly care for and protect the plantings. Considering the unusual stress of climatic and economic conditions, it is

gratifying that the percentage of failures is no higher than it is. It is felt that under the conditions obtaining the percentage of successes is very satisfactory and indicates not only the possibilities of

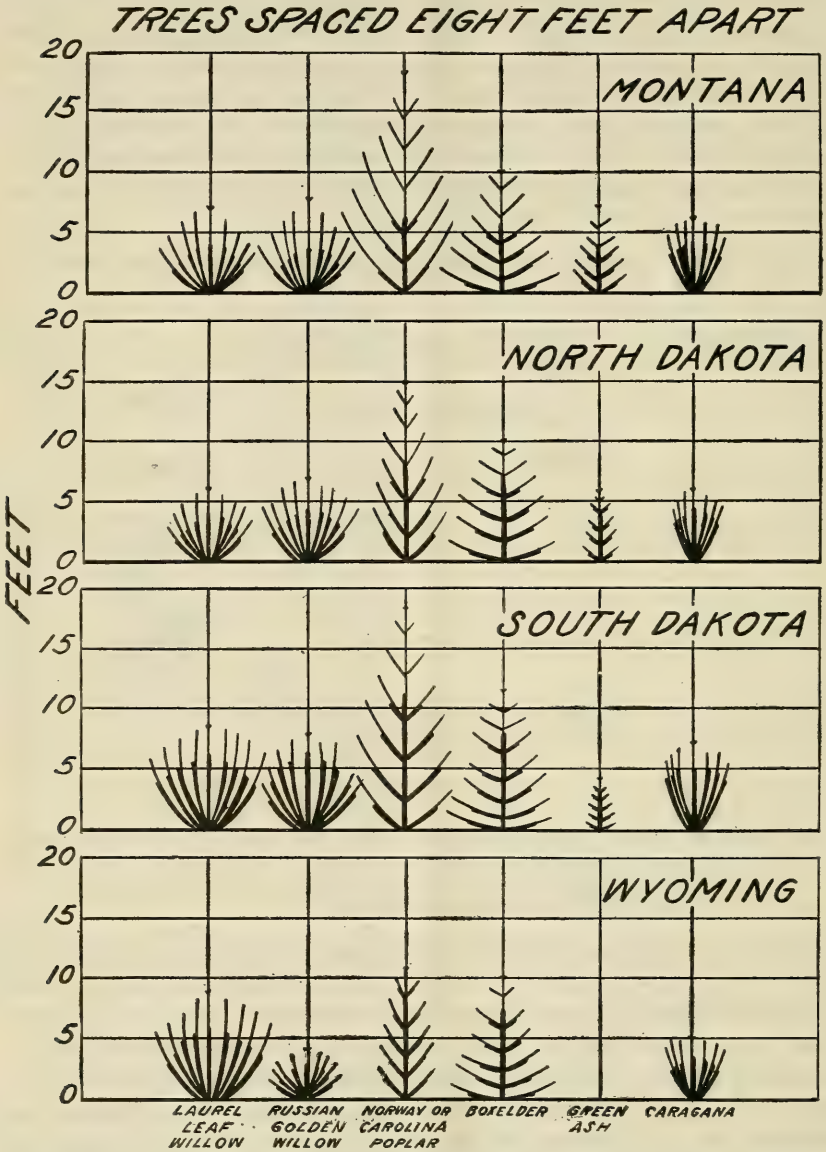

FIG. 13.—Diagrammatic representation of the average and maximum heights in 1920 of each species of tree planted as shelter belts in the States of Montana, North Dakota, South Dakota, and Wyoming in 1916. The heavy lines indicate the average growth and the light lines the maximum growth.

growing shelter belts but the interest the settlers and the farmers of the region have in them.

The actual area covered by the 716 plantings listed as successful at the close of the season of 1920 was 625 acres, or an average of 0.87 acre per planting. This acreage was divided among the four States as follows: Montana, 380 acres; North Dakota, 145 acres; South Dakota, 80 acres; and Wyoming, 20 acres.

Figure 12 is an outline map of the area in which each township (6 by 6 miles) in which one or more plantings had been made in 1917 or in which application had been made for planting in 1918 is represented by a dot. This shows the general distribution of the plantings.

TABLE 8.—*Percentage of trees of each species or kind of stock living at the end of the first season of growth each year from 1916 to 1920, inclusive.*

Year.	Plantings reported.	Species or kind of stock.									Total.
		Willow (cuttings).	Willow (rooted).	Poplar (cuttings).	Poplar (rooted).	Box elder.	Green ash.	Caragana.	White elm.	Chinese elm.	
1916	44.2	68.8	92.6	72.9	96.7	89.1	93.7	90.5	.....	.....	80.0
1917	63.4	.....	97.9	.....	.....	81.7	85.0	.....	81.2	.....	81.2
1918	34.4	.....	56.6	.....	.....	83.3	77.2	90.0	.....	88.8	72.2
1919	59.4	.....	45.6	.....	.....	72.3	68.5	78.6	.....	.....	59.4
1920	40.5	.....	.....	.....	.....	88.2	79.9	.....	.....	.....	84.8

Table 8 has been compiled from reports sent in by individual farmers at the end of each growing season. Reports are received on only about half the plantings. They contain an actual count of the dead trees and serve as a basis for furnishing replacements. Replacement planting is not practicable after the second season, as the new trees are not able to compete successfully with the older ones.

TABLE 9.—*Shelter belts planted in 1916 in which different tree species were still alive in 1920.*

State.	Plantings inspected.	Trees living (per cent).				
		Willow.	Poplar.	Box Elder.	Green ash.[1]	Caragana.
Montana	214	53.0	55.7	100	100	100
North Dakota	74	59.5	66.2	100	100	100
South Dakota	51	71.2	78.9	100	100	100
Wyoming[2]	10	60.0	50.0	100	.....	100

[1] Green ash was planted in all the shelter belts in North Dakota, but in only six in Montana, three in South Dakota, and none in Wyoming.
[2] Shelter belts in Wyoming were all in the southeastern part of the State, in Niobrara and Goshen Counties.

Table 8 shows for each year the percentage of each kind of stock living at the end of its first season in the ground and indicates the relative ease of establishing different species and kinds of stock. In the total of all species it indicates the degree of success that cooperating farmers have attained in starting their shelter belts. The high-

est percentage of stand was 84.8 in 1920 and the lowest 59.4 in 1919. The high percentage of stand in 1920 was at least partly due to the fact that only species that had proved hardy and easily established were used, while both willow and poplar are found in preceding years. The rainfall in 1916 was above normal, and in the four succeeding years it was below normal. The effect of the continued drought on the establishment of willow is clearly shown by the poor stands in 1918 and 1919 as compared with those in 1916 and 1917.

Elm does not appear after 1917. There has been no seed crop in the vicinity of Mandan from which to raise stock since that time.

GROWTH STUDY OF COOPERATIVE SHELTER BELTS PLANTED IN 1916.

During the summer of 1920 a special study was made of the shelter belts that were planted in 1916. Of 633 originally planted, as given in Table 8, 373 remained active at the beginning of the 1920 season. Of this number 349, or 94 per cent, form the basis for the data given in Tables 9 and 10.

Table 9 shows for each State the percentage of the shelter belts planted in 1916 in which the different species were living in 1920. In the 349 shelter belts studied, box elder, green ash, and caragana were living in every active planting, but willow and poplar survived in only one-half to three-fourths of the plantings active at that time. Both box elder and willow showed a better survival in South Dakota than in North Dakota, Montana, or Wyoming. This is probably due to the somewhat more favorable conditions of moisture and temperature that exist in South Dakota.

TABLE 10.—*Average and maximum height*[1] *in the summer of 1920 of the different species of trees in shelter belts planted in 1916.*

State.	Laurel-leaf willow.	Russian golden willow.	Norway or Carolina poplar.[2]	Box elder.	Green ash.	Caragana.
Montana:						
Average height ..... feet....	3.75	4.25	6.50	5.75	4.00	4.00
Maximum height ..... do....	7.00	7.50	18.00	10.00	7.00	6.00
North Dakota:						
Average height ..... do....	4.00	4.75	7.50	6.50	4.00	4.00
Maximum height ..... do....	6.00	7.00	15.00	10.00	5.50	5.50
South Dakota:						
Average height ..... do....	5.50	6.00	12.00	7.50	3.50	5.00
Maximum height ..... do....	9.00	7.00	18.00	11.00	4.00	7.00
Wyoming:						
Average height ..... do....	5.75	3.25	8.50	7.00	.....	3.00
Maximum height ..... do....	9.00	4.00	10.00	10.00	.....	5.00

[1] Two measurements were taken in each shelter belt for each species, one at a point judged to be the average height of the row and one where the trees were tallest. The maximum height given is the highest measurement found in any planting in the State.

[2] The Norway poplar and Carolina poplar were so similar in appearance that no attempt was made to distinguish between them.

In each of the 349 shelter belts studied, measurements were made of the average and maximum height of each species. A summary of

the results of this study is given in Table 10, which shows for each species the average height attained in all plantings in each State and the maximum height attained in any planting in the State.

The low average heights of willow and poplar as compared to the maximum heights are due to the continual freezing back of these species in most of the plantings. It will be noted that with the exception of green ash, all of the species made the best growth in South Dakota. As the figures for green ash in that State are based on three plantings only, they can not be considered adequate. Subsequent plantings have shown the same relatively higher growth for green ash. The comparatively better conditions as to rainfall and temperature which prevail in South Dakota will probably explain this increased growth. The data given in Table 10 are shown diagramatically in Figure 13.

FIG. 14.—An unpruned shelter belt in the third summer of growth. Planting in Valley County, Mont.

EXPERIMENTAL PLANTINGS.

In addition to the shelter-belt demonstrations under actual farm conditions, a number of special experimental plantings have been made at the Northern Great Plains Field Station.

Species testing blocks.—Since 1914 more than 80 different species of trees have been planted as pure stands in blocks containing approximately 100 trees each. These plantings are intended to serve primarily as hardiness tests. Some of the most important results from this work have been embodied in the discussion under the heading "Notes on tree species," page 6.

Methods of care for shelter belts.—Ten blocks of identical shelter-belt plantings similar to the regular demonstrations were set out in

1918. In five of the blocks the trees are spaced 4 by 4 feet and in the others 4 by 8 feet. One block of each rate of planting is not pruned, one block is moderately pruned, one block is severely pruned, one block is mulched, and one is neglected (given no cultivation). The first three blocks are given clean cultivation; the last two are not pruned.

An unpruned shelter belt in its third summer of growth in Valley County, Mont., is shown in Figure 14. A severely pruned shelter belt of the same age in Grant County, N. Dak., is shown in Figure 15. Both the effectiveness of the shelter belt and its ability to protect itself is destroyed by pruning.

Two other blocks were planted in which 4 by 12 and 8 by 8 feet spacing distances, respectively, were used. These blocks were not pruned and were given clean cultivation and with the other unpruned

FIG. 15.—A severely pruned shelter belt in the third summer of growth. Planting in Grant County, N. Dak.

blocks form a series of spacing tests. It is yet too early to present results from this series of experiments.

Species combinations.—A number of plantings were made in 1915 in which different tree species were arranged in varying combinations. This experiment was designed to determine the ability of the different species to compete with each other in adjacent rows.

SUMMARY AND CONCLUSIONS.

During the 5-year period from 1916 to 1920, inclusive, 1,234 cooperative demonstration shelter belts were planted in the Great Plains area of Montana, North Dakota, South Dakota, and Wyoming. Of this number, 716 were still growing at the close of the summer of 1920. A total of 1,488,658 trees were used in making these plantings.

Of the tree species extensively tested, the following seem adapted to the climatic conditions generally prevailing: Box elder, green ash, white elm, and caragana.

The following species which have so far been tested only in a limited way give promise of being suitable for general planting: Northwest poplar, chokecherry, buffalo berry, Russian olive, Black Hills spruce, white spruce, blue spruce, Scotch pine, and jack pine.

Extensive tests of the following species show that they are not adapted for general planting: Norway poplar, Carolina poplar, Russian golden willow, and laurel-leaf willow.

Careful preparation of the soil before planting, to conserve moisture and work out grass and weeds, is a prime requisite for successful tree planting. Clean summer fallow is the best tillage method to practice for this purpose.

Clean cultivation after planting is essential to the continued growth of young trees. Neglect in this respect for a single season is likely to result in serious damage to the trees.

Insect and animal pests may cause considerable damage unless precautions are taken against them.

With such trees as box elder, green ash, and white elm, stock raised from seed procured from native trees has shown greater hardiness than that coming from more southern and eastern localities. Seed for propagating any species for planting in shelter belts on the northern Great Plains should come from a northern source.

A standard spacing distance for trees in shelter belts has not yet been determined. Present data indicate that for the average planting site in the area the 4 by 8 feet distance used in these demonstrations is too close. Further information is needed on this point.

The experience of these five years of tree planting has shown conclusively that it is possible to start successfully a planting of trees on the average upland farm site in the northern Great Plains. Future investigation must show whether or not it is possible for such plantings to maintain themselves after they have attained their maximum growth.

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UNITED STATES DEPARTMENT OF AGRICULTURE

BULLETIN No. 1114

Washington, D. C. PROFESSIONAL PAPER August 30, 1922

THE DETECTION OF HYPOCHLORITES AND CHLORAMINS IN MILK AND CREAM.

By PHILIP RUPP, *Dairy Chemist, Dairy Division, Bureau of Animal Industry.*

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The use of hypochlorites and chloramins in the treatment of dairy utensils has led to much speculation as to whether or not attempts might be made to add these preparations to milk. This speculation is due to the fact that there have been no methods for detecting small amounts of chlorin in milk. The term "chlorin," as used in this paper, refers to the available chlorin derived from hypochlorites and chloramins.

OUTLINE OF EXPERIMENTAL WORK.

Very small quantities of chlorin in water solution can easily be detected, either by means of the iodid-starch or the *o*-toluidin test. However, when applied to milk containing small amounts of chlorin, these tests are of no value, because the chlorin has combined with the protein of the milk and is not liberated readily at room temperature by the addition of acids.

It seemed desirable, therefore, to devise some methods for the demonstration of small amounts of hypochlorites or chloramins in milk and cream. The question first arose, how firmly is the chlorin united with the protein? If loosely combined, there was no reason why it should not be liberated under proper conditions.

On experiment it was found that the chlorin could be liberated; and if liberated in the presence of potassium iodid, the chlorin would displace the iodin of the iodid, which would then combine

with the protein, giving rise to a yellow-colored compound, the shade of the color depending on the amount of iodin liberated. If, however, only small amounts of iodin were liberated, then the colored protein compound would be masked by the large excess of unaltered protein. The small amount of colored protein could then be made to react with starch, producing a blue color which could be more readily discerned, thus making the test more delicate.

In order to determine in what dilution the hypochlorites and chloramins can be detected in milk and cream a series of solutions, each containing 100 cubic centimeters of milk or cream plus definite amounts of hypochlorite or chloramin solution, were prepared, so that the final results were solutions containing chlorin from 1:1,000 to 1:100,000 parts of milk or cream. The flasks containing these solutions were placed in the ice box for 24 hours and then examined for chlorin. After standing at room temperature for several hours, the flasks were returned to the ice box, and again examined after 48 hours. A flask of plain milk was added as a control.

PREPARATION OF REAGENTS.

(*a*) *Potassium iodid solution.*—Dissolve 7 grams of potassium iodid in 100 cubic centimeters of distilled water. Prepare fresh.

(*b*) *Hydrochloric acid.*—To 100 cubic centimeters of concentrated hydrochloric acid add 200 cubic centimeters of distilled water.

(*c*) *Starch solution.*—Boil 1 gram of starch in 100 cubic centimeters of distilled water. Cool before using.

THE TEST.

(1) To 5 cubic centimeters of milk or cream in a medium-sized test tube add 1.5 cubic centimeters of the iodid solution, mix thoroughly by shaking, and observe the color of the milk.

(2) If unaltered, add 4 cubic centimeters of hydrochloric acid, mix thoroughly by means of a glass rod flattened at one end, and note the color of the curd.

(3) Next place the tubes in a large water bath, previously heated to 85° C., and allow to remain for 10 minutes. During this interval the curd will have risen to the surface.

(4) The tubes are then cooled rapidly by placing in cold water, and when cold are examined for any color change that may have taken place, either in the curd or in the liquid below.

(5) Finally, add 0.5 to 1 cubic centimeter of starch solution to the liquid below the curd and note the result.

REACTION IN MILK.

Milk containing 1 part of chlorin in 1,000 parts of milk acquires a distinct reddish color, while at 1:2,500 dilution it is still slightly

discolored when compared with the control. This holds good for both hypochlorites and chloramins.

In case the milk contains an amount of hypochlorite corresponding approximately to 1 part of chlorin in 5,000 parts of milk, then the milk acquires a pale-yellow color on the addition of the iodid solution, and the color deepens as the amount of chlorin increases, so that at 1:1,000 dilution the milk has a yellowish-brown color. At 1:5,000 dilution the yellow color is not permanent and fades gradually. If kept at room temperature it is necessary to add hydrochloric acid at 1:5,000 dilution in order to bring out the yellow color. With chloramins a yellow color is produced at 1:2,500 dilution. If less chlorin is present than mentioned above, the milk retains its natural color.

In more dilute solutions of hypochlorites and chloramins it is necessary to heat the milk-iodin-hydrochloric-acid mixture in order to bring about the reaction. The cooling is necessary to prevent a too rapid decomposition of the iodid by the excess of hydrochloric acid.

With hypochlorites and chloramins the curd and the solution below acquire a distinct pale-yellow color with 1 part of chlorin in 50,000 parts of milk. The shade of the color varies somewhat and is a little paler with chloramins than with hypochlorites. The liquid below the curd is also colored yellow, the shade corresponding to the depth of color of the curd.

When milk which has stood at room temperature for 24 hours is treated as above, the coloration produced is a little paler than when kept at ice-box temperature.

The curd of the control which has been kept at ice-box temperature shows only a slight yellowish tinge when compared with the curd of a blank which contains no iodid. The liquid below the curd in the control, however, is most distinctive, since it shows no trace of yellow when compared with the blank containing no iodid.

The addition of starch to the liquid below the curd brings out the reaction somewhat more prominently by changing the pale-yellow color to a light-reddish purple, the coloration passing through red purple into a deep-blue purple as the amount of the chlorin present increases. The control is also slightly discolored by the addition of starch and may acquire a light-straw color, but without any trace of a red-purple tint.

In milk which has been kept at room temperature for a long time, the control may have a stronger straw color, but without any trace of purple. On this account it is best to judge the presence of small amounts of hypochlorites and chloramins by the color of both the curd and the liquid below.

TABLE 1.—*The hypochlorite test in tabular form.*[1]

Test.	Parts of available chlorin with different color reactions.					
	1:1,000	1:2,500	1:5,000	1:10,000	1:25,000	1:50,000
Take 5 c.c. milk	Reddish color.	Slightly discolored.				
Add 1.5 c.c. iodid solution. Milk appears.	Yellowish brown.	Deep yellow.	Pale yellow, fades.			
Add 4 c.c. HCl. Curd appears.	Yellowish brown.	Deep yellow.	Light yellow			
After heating at 85° C. and cooling, the curd and liquid below appear.	Yellowish brown.	Deep yellow.	Yellow	Yellow	Pale yellow.	Yellowish.
Add 0.5 c.c. starch solution. Liquid below curd appears.	Blue purple.	Blue purple.	Blue purple.	Dark-red purple.	Red purple.	Pale-red purple.

[1] The test for chloramins is approximately the same.

REACTION IN PASTEURIZED MILK.

If hypochlorite solution is added to milk in different proportions and the milk is then pasteurized at 145° F. for 30 minutes, the results obtained by the above test after the milk has been kept in the ice box for 24 hours are approximately the same as with raw milk.

REACTION IN CREAM.

Hypochlorites or chloramins added to 20 per cent cream in different proportions give results approximately the same as with milk.

With 1 part of chlorin in 2,500 parts of cream, the cream turns yellow on adding the iodid solution. At 1:5,000 dilution and above, no change is apparent after adding hydrochloric acid to the cream-iodid mixture, and it is necessary to heat the cream in order to bring about the reaction. At 1:25,000 dilution both the curd and the liquid below are a pale yellow, while at 1:50,000 dilution the curd is a little more yellow than the control and the liquid below is the same as in the control. After adding starch to the liquid below the curd, it acquires a pale-red purple color with hypochlorites at 1:50,000 dilution, while with chloramins it remains the same as the control at this dilution. At 1:25,000 dilution the reaction is distinct with chloramins.

After heating the cream-iodid-hydrochloric-acid mixture, the presence of small amounts of chlorin must be judged by the color of the liquid below the curd, because the curd, owing to the presence of the fat globules, has a pale-yellowish color. The yellow color of the curd becomes more marked as the amount of chlorin present increases, while the liquid below the curd has the same color as in milk.

The above test applies equally well after the milk or cream has been kept in the ice box for 48 hours.

Before applying the above test for the detection of chlorin in milk or cream, it is advisable to prepare a series of flasks containing hypochlorite solution in different proportions in order to become acquainted with the coloration produced.

The test becomes more delicate by using 2 cubic centimeters of the iodid solution, but has the disadvantage that the controls of certain old milks give a slight reaction on the addition of starch.

SUMMARY.

1. A test for the detection of hypochlorites and chloramins in milk and cream by means of potassium iodid and hydrochloric acid has been described.

2. One part of chlorin in 50,000 parts of milk or cream can be detected by this method.

3. Milk kept in the ice box for 24 and 48 hours still gives the reaction.

4. Milk kept at room temperature for 24 hours gives the reaction, but a little less marked than if kept cold.

5. Milk pasteurized, after the addition of hypochlorites, at 145° F. for 30 minutes reacts the same as raw milk.

6. Twenty per cent cream gives the reaction in approximately the same degree as raw milk.

7. It is best to judge the presence of added hypochlorites or chloramins by the color of both the curd and the liquid below the curd.

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UNITED STATES DEPARTMENT OF AGRICULTURE

BULLETIN No. 1115

Washington, D. C. November 28, 1922

CHEMICAL CHANGES IN CALCIUM ARSENATE DURING STORAGE.

By C. C. McDonnell, *Chief*, and C. M. Smith, *Assistant Chemist, Insecticide and Fungicide Laboratory, Miscellaneous Division, Bureau of Chemistry*, and B. R. Coad, *Entomologist in Charge, Delta Laboratory, Bureau of Entomology*.[1]

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PURPOSE OF INVESTIGATION.

Soon after calcium arsenate had been introduced into the Cotton Belt for use in the control of the cotton boll weevil, the United States Department of Agriculture began to receive complaints of injury to cotton plants resulting from the application of this material. Chemical analyses showed that much of the calcium arsenate being used in the cotton-growing region at that time contained from 1 to 5 per cent of "water-soluble" arsenic oxid,[2] which explained to some extent the injury that was being done to the plants.

In an endeavor to place the responsibility for this unsatisfactory condition, it was suggested that perhaps commercial calcium arsenates deteriorated somewhat when stored for a period of several weeks or months and that this deterioration was more rapid under the climatic conditions existing in the cotton-growing States. This problem was a very serious one, not only from the standpoint of the consumer but from that of the manufacturer as well, for on its solution depended the answer to the question whether or not it was

[1] L. N. Markovitz and A. Shaver, junior chemists, of the Bureau of Chemistry, assisted in the analytical work, and T. P. Cassidy and M. T. Young, of the Bureau of Entomology, cared for and sampled all the material stored at Tallulah, La.

[2] As determined by the official method of the Association of Official Agricultural Chemists, J. Assn. Offic. Agr. Chemists, 5 (1921): 37.

3835°—22——1

safe to use calcium arsenate that had been stored for any appreciable length of time. A preliminary investigation showed that in the cases of the most serious burning reported, the injury was due to the use of improperly made calcium arsenate. The evidence of deterioration seemed sufficiently suggestive, however, to warrant an investigation of the matter under accurately controlled conditions.

RESULTS OF PREVIOUS INVESTIGATIONS.

Robinson[3] showed that chemical changes occur in calcium arsenate through the action of carbon dioxid in the presence of water and stated that under atmospheric conditions a similar but much slower action probably would occur. As a result of bubbling carbon dioxid through suspensions of dicalcium and tricalcium arsenates in water, he concluded that there was an evident "solvent action upon the calcium arsenates." However, while this writer's results for tricalcium arsenate were higher, those for dicalcium arsenate were lower than his figures for the solubility of the same salts in pure water.

Patten and O'Meara[4] suggested that calcium arsenate when applied to foliage would almost certainly be subject to change by the carbon dioxid given off by the leaves. In pursuance of this idea, they determined the amount of arsenic rendered soluble when saturated carbon dioxid water was used in place of distilled water in the regular method for determining water-soluble arsenic oxid in calcium arsenate. The six samples used by them gave an average of 0.7 per cent soluble arsenic oxid with distilled water and an average of 18.5 per cent soluble arsenic oxid with the carbonated water.

The work of the previous investigators was done in connection with the action of carbon dioxid on calcium arsenate when applied to foliage in a thin film and subjected to the effect of moisture. Reedy and Haag,[5] the only workers who have considered the question of a possible change in calcium arsenate during storage, state that "during storage this product undergoes some change in composition which results in a considerable increase in the amount of water-soluble arsenate." They thought at first that moisture and carbon dioxid from the air caused this change, but state that "the use of air-tight containers has not been sufficient to prevent it." However, they report experiments showing that exposure to laboratory air and to moist carbon dioxid caused an increase in the water-soluble arsenic which in the latter case was quite marked. As a result of their work, they conclude that "the decomposition of tricalcium arsenate is due to hydrolysis, which seems to be catalyzed by many substances that

[3] J. Agr. Research, 13 (1918): 288; Oregon Agr. Col. Exp. Sta. Bull. 131 (1918), p. 10.
[4] Mich. Agr. Col. Exp. Sta., Quart. Bull., Nov., 1919, p. 83.
[5] J. Ind. Eng. Chem., 13 (1921): 1038.

may be present as impurities." The results presented are not sufficient to substantiate this conclusion in so far as it applies to deterioration during storage.

RESULTS OF PRESENT INVESTIGATION.

The United States Department of Agriculture recommends the application of calcium arsenate on cotton only in the form of a dust. All of the work here reported, therefore, was done on calcium arsenate in the dry powdered form.

It was realized that if chemical changes occur in calcium arsenate during storage, the type of container in which it is stored, as well as the original composition of the material and the climatic conditions under which it is stored might have an influence on the rate of this change. The plan as outlined therefore was to obtain material representing all of the leading commercial brands on the market and all of the principal types of commercial containers. Two original containers of calcium arsenate from six of the largest manufacturers of this material were stored in a frame warehouse at the Delta Laboratory of the Bureau of Entomology at Tallulah, La. One container of each of these six brands was put in storage intact and disturbed only at stated intervals when samples for analysis were drawn. The material in the other six packages was subdivided, 25-pound portions in each case being put into various standard types of containers and the remaining material, from 50 to 100 pounds, retained in the original container. Four other samples, three of which represented brands included in the six just mentioned, were placed in storage in the building occupied by the Insecticide and Fungicide Board (220 Thirteenth Street SW, Washington, D. C.). These were not subdivided. Samples were drawn at intervals from all of these containers for analysis.[6]

The following scheme of marking for the identification of the various brands of calcium arsenate, the place of storage, and the kind of container, was adopted: Brands or manufacturers, *A*, *B*, *C*, *F*, *H*, *I*, and *J*; material stored in Washington, *W*, immediately after the letter designating the manufacturer; material stored in Tallulah, in original containers and without subdivision, *T*; sets that were subdivided and used for the container tests, *S*. All subdivisions were stored at Tallulah.

COMPOSITION OF ORIGINAL SAMPLES.

The results of the analyses of the samples made at the time of collection are given in Table 1.

[6] In sampling the material was disturbed as little as possible. Several cores were taken by means of a trier, about 1¼ inches in diameter, at various places and extending at different angles from the top of the package to the bottom. The head of the container was immediately replaced, or the holes through which the trier was inserted were tightly closed.

TABLE 1.—*Composition of calcium arsenates at the beginning of the period of storage.*

Sample.	Arsenic oxid (As_2O_5).	Calcium oxid (CaO).	Magnesium oxid (MgO).	Lead oxid (PbO).	Copper oxid (CuO).	Oxids of iron and aluminum (R_2O_3).	Antimonic oxid (Sb_2O_5).	Acid-insoluble material.	Loss on ignition.	Total.	Carbon dioxid (CO_2).	Water-soluble arsenic oxid (As_2O_5).
	Per ct.	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*
AT	40.55	43.16	1.82	Trace.	.....	0.44	0.02	0.45	10.88	97.32	2.31	0.02
AS	40.18	39.76	1.88	0.91	.....	2.51	.05	.44	10.24	95.97	2.78	.08
AW	42.95	42.76	1.41	Trace.	.....	.40	.07	.16	8.96	96.71	1.78	.08
BT	41.12	40.57	1.34	Trace.	.....	.66	.16	.23	13.90	97.98	3.62	.20
BS	40.81	38.96	1.78	0.70	0.70	2.10	.19	.57	11.40	97.21	5.30	.35
BW	40.58	39.89	2.08	Trace.	.....	1.12	.21	.62	11.85	96.35	3.44	.69
CT	39.35	36.92	.22	9.48	.....	.52	.53	.24	8.85	96.11	3.30	.83
CS	41.59	43.06	.38	.77	.....	.38	.50	.44	8.99	96.11	4.47	.15
FT	44.10	43.80	.48	.63	.....	1.42	.14	.62	4.88	96.07	1.40	.00
FS	45.07	42.87	.32	.77	.....	1.41	.21	.45	5.05	96.15	1.91	.03
HT	41.58	41.04	.82	.72	.....	2.22	.11	1.08	6.72	94.29	1.33	.10
HS	42.37	42.05	1.33	.70	.....	1.54	.11	1.00	6.33	95.43	1.07	.10
HW	43.10	40.35	3.37	.28	.....	2.08	.07	1.09	6.86	97.20	.91	.11
IT	40.91	43.16	.75	1.36	.....	1.50	.08	.71	8.05	96.52	5.95	.08
IS	44.40	43.16	.53	.73	.....	.86	.19	.77	6.08	96.72	5.69	.39
JW	45.65	40.55	1.18	.32	.....	.92	.29	.32	5.37	94.60	2.69	.30

It will be noted that the arsenic oxid content exceeds 40 per cent in every case, except that of the sample containing lead, and that the calcium oxid and arsenic oxid values are approximately equal. This is as it should be in a properly made calcium arsenate to be used for insecticidal purposes. The impurities are low in all cases except one, sample *CT*, which contains more than 9 per cent of lead expressed as the oxid. This is probably present in the form of lead arsenate as a result of carelessness in manufacture. The presence of small quantities of lead in the other samples is doubtless caused by the use in their manufacture of apparatus that had previously been employed in making lead arsenate. The copper in sample *BS* apparently owed its origin to the presence of Bordeaux mixture, as small pieces of a blue material resembling this product were visible. The water-soluble arsenic oxid figures are reasonably low in all cases except two, one of which is the sample containing an appreciable quantity of lead.

CARBON DIOXID AND WATER-SOLUBLE ARSENIC OXID IN STORED SAMPLES.

The chemical criterion employed in the estimation of deterioration in calcium arsenate is the change in the so-called water-soluble arsenic oxid. All of the work quoted from the literature showed that contact with carbon dioxid in the presence of water may greatly increase the content of soluble arsenic oxid. The authors' experience accords with this. When carbon dioxid is bubbled through an aqueous suspension of commercial calcium arsenate for a sufficient length of time, the quantity of arsenic oxid rendered soluble is approximately the same as that obtained when dicalcium arsenate is treated with water alone, in the same concentration. Further, calcium carbonate, under ordinary conditions, neutralizes arsenic acid only to the dicalcium arsenate stage, showing that a basic mixture tends to revert, by

the absorption of carbon dioxid, to a mixture of calcium carbonate and dicalcium arsenate. It appeared that any increase in water-soluble arsenic oxid in commercial calcium arsenate during storage, therefore, would probably be the result of absorption of carbon dioxid from the air.

Accordingly, the authors decided to determine both carbon dioxid and water-soluble arsenic oxid in all of the samples and subdivisions at successive intervals. Soluble arsenic oxid was determined by the official method of the Association of Official Agricultural Chemists and carbon dioxid in a specially designed apparatus similar to that described by W. H. Chapin.[7] This method did not give extremely accurate results but it is very rapid and sufficiently accurate for this work. Duplicate determinations seldom differed by more than 0.10 per cent. The fact that the results here vary more than this from the curves drawn may be explained on the basis of uneven distribution of the material in the barrels and the method of sampling. The subsamples were always thoroughly mixed, but they were taken from the barrels by means of a trier, and, since carbon dioxid must work its way through from the outside of the package, it is reasonable to suppose that three or four trierfulls might not always remove a strictly representative sample. Taken as a whole, however, the results leave no doubt of the fact that carbon dioxid is absorbed under certain conditions.

The results of these examinations are reported in Table 2 and are also shown graphically in Figures 1 to 46. The results on all the samples obtained from one manufacturer are presented before those of another are shown. Within each of these groups the order is as follows: Unsubdivided sample kept at Washington; unsubdivided sample kept at Tallulah; portion of subdivided sample kept at Tallulah in original container; subdivided samples at Tallulah representing the different container tests. The last subdivisions are indicated by figures following the letter designation as follows: 1, sheet-iron drum; 2, unlined sugar barrel; 3, paper-lined sugar barrel; 4, heavy hardwood barrel; 5, unlined veneer drum; 6, paper-lined veneer drum.

In every graph the arsenic oxid values are represented by a solid line and the carbon dioxid values by a broken line. The curves are drawn in what seemed to be the most probable positions without attempting to calculate them. In order to bring out more clearly the relationship between their variations, the ordinate scale of arsenic oxid (As_2O_5) values has been magnified to five times that of the carbon dioxid (CO_2) values. The horizontal spaces on all the plots indicate intervals of three months, the initial ordinate representing in each case December 1, 1919.

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[7] J. Ind. Eng. Chem., **10** (1918): 527.

TABLE 2.—*Effect of storage on chemical composition of calcium arsenate.*

Sample examined.	Date sampled.	Period of storage.	Water-soluble arsenic oxid (As_2O_5).	Carbon dioxid (CO_2).
		Mos.	*Per ct.*	*Per ct.*
AW (100 pounds in hardwood barrel)	1920.			
	Apr. 12	.....	0.08	1.78
	June 23	2.4	.07	1.88
	1921.			
	Jan. 14	9.1	.07	1.90
	July 20	15.3	.10	1.84
	Nov. 25	19.4	.08	1.92
	1922.			
	Mar. 1	22.6	.08	.....
AT (200 pounds in hardwood barrel)	1919.			
	Dec. 1	.....	.02	2.38
	1920.			
	Jan. 8	1.2	.05	2.35
	Feb. 6	2.2	.05	2.36
	Mar. 6	3.2	.02	2.41
	Apr. 7	4.2	.03	2.41
	May 4	5.1	.05	2.46
	June 10	6.3	.04	2.70
	July 14	7.4	.05	2.84
	Aug. 14	8.4	.05	2.99
	Sept. 17	9.5	.05	2.55
	Oct. 15	10.5	.06	2.58
	Nov. 17	11.5	.05	3.18
	Dec. 15	12.5	.06	3.28
	1921.			
	Jan. 15	13.5	.05	3.52
	Apr. 2	16.0	.04	3.11
	July 1	19.0	.08	4.12
	Oct. 1	22.0	.17	4.88
	1922.			
	Jan. 2	25.0	.10	3.55
AS (50 pounds in hardwood barrel)	1920.			
	Apr. 20	.....	.08	2.78
	June 10	1.7	.02	2.53
	July 14	2.8	.03	2.72
	Aug. 14	3.8	.02	2.64
	Sept. 17	4.9	.04	2.65
	Oct. 15	5.8	.02	2.72
	Nov. 17	6.9	.02	2.64
	Dec. 15	7.8	.05	3.26
	1921.			
	Jan. 15	8.8	.05	3.13
	Apr. 2	11.4	.06	3.42
	July 1	14.3	.09	4.64
	Oct. 1	17.3	.07	4.53
	1922.			
	Jan. 2	20.4	.15	5.30
AS-1 (25 pounds in metal drum)	1920.			
	Apr. 20	.....	.07	2.92
	June 10	1.7	.03	2.85
	July 14	2.8	.03	2.50
	Aug. 14	3.8	.02	2.47
	Sept. 17	4.9	.02	2.46
	Oct. 15	5.8	.02	2.62
	Nov. 17	6.9	.02	2.53
	Dec. 15	7.8	.04	2.76
	1921.			
	Jan. 15	8.8	.05	2.83
	Apr. 2	11.4	.05	2.78
	July 1	14.3	.05	2.60
	Oct. 1	17.3	.05	2.52
	1922.			
	Jan. 2	20.4	.04	2.58
AS-2 (25 pounds in unlined sugar barrel)	1920.			
	Apr. 20	.....	0.06	2.94
	June 10	1.7	.03	3.04
	July 14	2.8	.05	3.85
	Aug. 14	3.8	.04	4.11
	Sept. 17	4.9	.07	4.41
	Oct. 15	5.8	.07	4.94
	Nov. 17	6.9	.13	4.97
	Dec. 15	7.8	.17	5.50
	1921.			
	Jan. 15	8.8	.17	5.57
	Apr. 2	11.4	.25	5.81
	July 1	14.3	.30	6.23
	Oct. 1	17.3	.33	6.08
	1922.			
	Jan. 2	20.4	.35	6.20
AS-3 (25 pounds in paper-lined sugar barrel)	1920.			
	Apr. 20	.....	.05	2.93
	June 10	1.7	.05	3.56
	July 14	2.8	.04	3.27
	Aug. 14	3.8	.05	4.22
	Sept. 17	4.9	.07	4.51
	Oct. 15	5.8	.05	4.04
	Nov. 17	6.9	.24	5.74
	Dec. 15	7.8	.20	5.65
	1921.			
	Jan. 15	8.8	.25	5.80
	Apr. 2	11.4	.34	6.03
	July 1	14.3	.30	6.04
	Oct. 1	17.3	.33	6.15
	1922.			
	Jan. 2	20.4	.37	6.24
AS-4 (25 pounds in hardwood barrel)	1920.			
	Apr. 20	.....	.05	2.83
	June 10	1.7	.06	3.15
	July 14	2.8	.07	4.18
	Aug. 14	3.8	.07	4.82
	Sept. 17	4.9	.26	5.83
	Oct. 15	5.8	.37	6.18
	Nov. 17	6.9	.38	6.14
	Dec. 15	7.8	.38	6.22
	1921.			
	Jan. 15	8.8	.37	6.02
	Apr. 2	11.4	.36	6.10
	July 1	14.3	.39	6.22
	Oct. 1	17.3	.42	6.18
	1922.			
	Jan. 2	20.4	.44	6.49
AS-5 (25 pounds in unlined veneer drum)	1920.			
	Apr. 20	.....	.05	3.01
	June 10	1.7	.03	2.87
	July 14	2.8	.04	3.19
	Aug. 14	3.8	.05	3.66
	Sept. 17	4.9	.05	3.68
	Oct. 15	5.8	.02	3.64
	Nov. 17	6.9	.05	3.95
	Dec. 15	7.8	.07	4.59
	1921.			
	Jan. 15	8.8	.12	5.04
	Apr. 2	11.4	.19	5.28
	July 1	14.3	.20	5.78
	Oct. 1	17.3	.31	5.86
	1922.			
	Jan. 2	20.4	.35	6.03

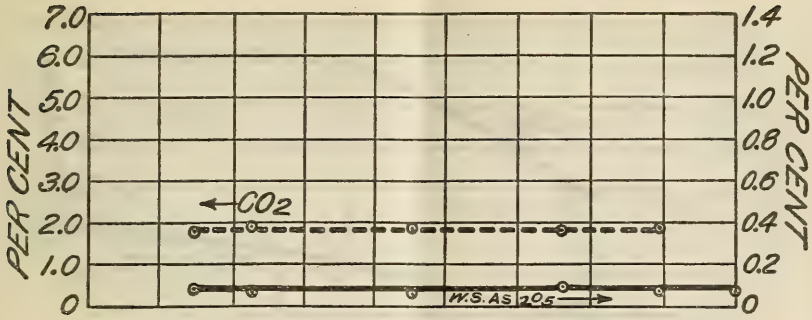

FIG. 1.—Sample AW (100 pounds in hardwood barrel).

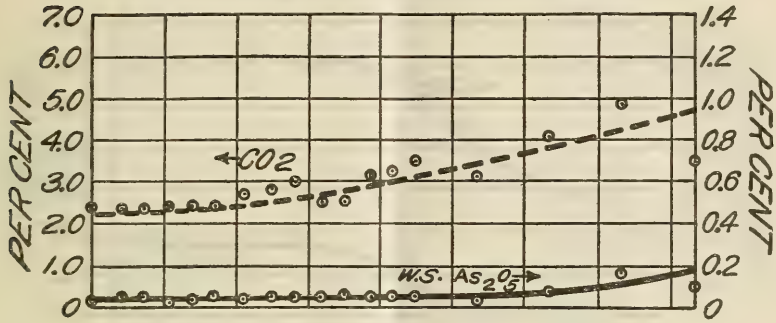

FIG. 2.—Sample AT (200 pounds in hardwood barrel).

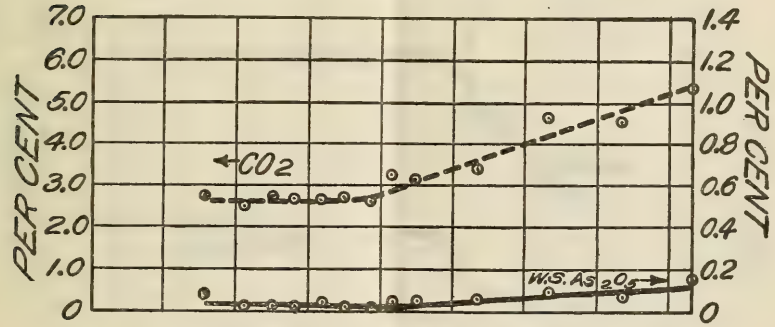

FIG. 3.—Sample AS (50 pounds in hardwood barrel).

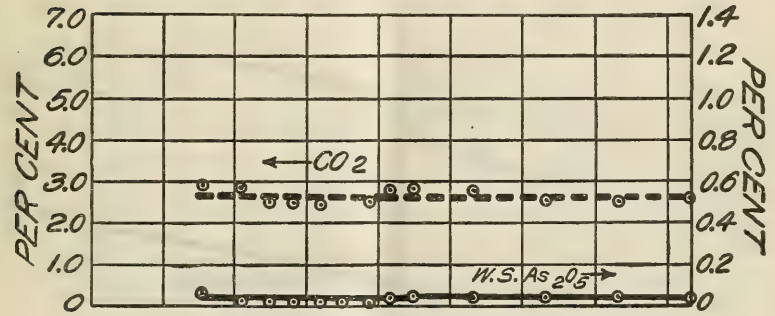

FIG. 4.—AS-1 (25 pounds in metal drum).

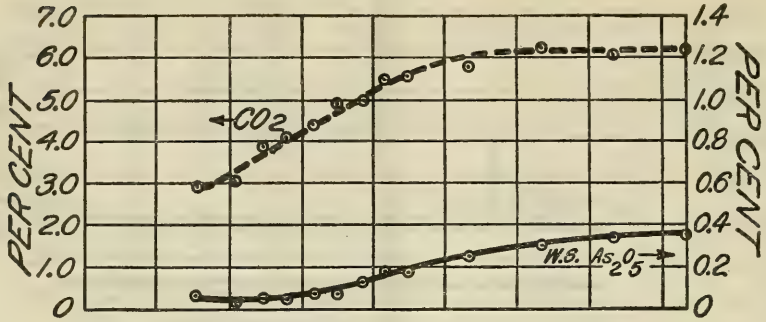

FIG. 5.—AS-2 (25 pounds in unlined sugar barrel).

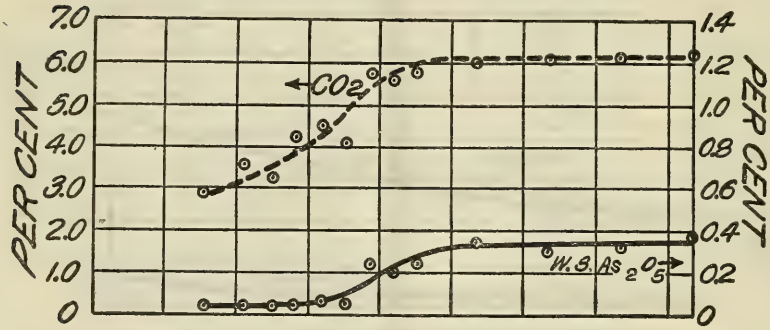

FIG. 6.—AS-3 (25 pounds in paper-lined sugar barrel).

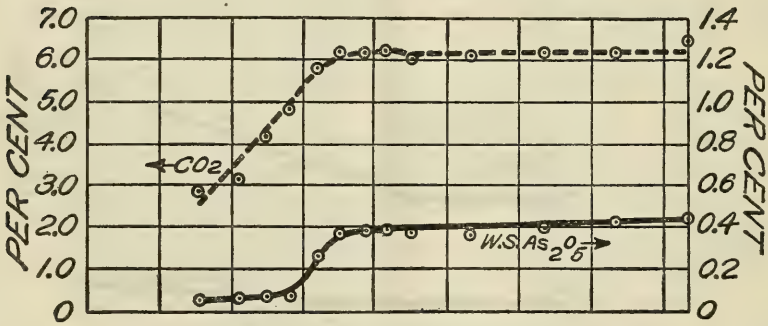

FIG. 7.—AS-4 (25 pounds in hardwood barrel).

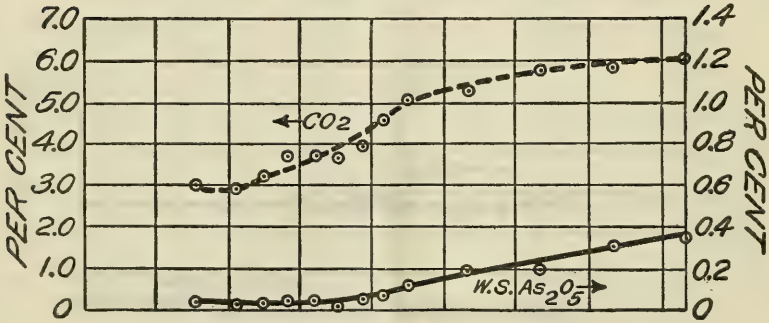

FIG. 8.—AS-5 (25 pounds in unlined veneer drum).

TABLE 2.—*Effect of storage on chemical composition of calcium arsenate*—Continued.

Sample examined.	Date sampled.	Period of storage.	Water-soluble arsenic oxid (As_2O_5).	Carbon dioxid (CO_2).
		Mos.	*Per ct.*	*Per ct.*
AS-6 (25 pounds in paper-lined veneer drum)..	1920.			
	Apr. 20	.....	0.05	2.86
	June 10	1.7	.03	2.85
	July 14	2.8	.04	2.67
	Aug. 14	3.8	.05	2.88
	Sept. 17	4.9	.02	3.08
	Oct. 15	5.8	.02	2.80
	Nov. 17	6.9	.05	3.64
	Dec. 15	7.8	.06	3.47
	1921.			
	Jan. 15	8.8	.08	3.92
	Apr. 2	11.4	.05	4.00
	July 1	14.3	.12	5.38
	Oct. 1	17.3	.13	5.02
	1922.			
	Jan. 2	20.4	.23	5.58
BW (100 pounds in paper-lined sugar barrel)...	1920.			
	Apr. 12	.....	.69	3.44
	June 23	2.4	.46	3.47
	1921.			
	Jan. 14	9.1	.82	3.63
	July 20	15.3	.71	3.86
	Nov. 26	19.4	1.11	4.01
	1922.			
	Mar. 1	22.6	1.09	.....
BT (100 pounds in hardwood barrel).....	1919.			
	Dec. 1	.....	.20	3.62
	1920.			
	Jan. 8	1.2	.23	3.68
	Feb. 6	2.2	.22	3.68
	Mar. 6	3.2	.27	3.70
	Apr. 7	4.2	.30	3.76
	May 4	5.1	.16	3.70
	June 10	6.3	.19	3.98
	July 14	7.4	.18	4.01
	Aug. 14	8.4	.17	3.82
	Sept. 17	9.5	.17	3.80
	Oct. 15	10.5	.22	4.28
	Nov. 17	11.5	.27	4.36
	Dec. 15	12.5	.27	4.82
	1921.			
	Jan. 15	13.5	.27	4.70
	Apr. 2	16.0	.20	4.14
	July 1	19.0	.28	4.68
	Oct. 1	22.0	.33	4.74
	1922.			
	Jan. 2	25.0	.31	4.72
BS (50 pounds in paper-lined sugar barrel)...	1920.			
	Apr. 20	.....	.35	5.30
	June 10	1.7	.25	4.93
	July 14	2.8	.28	4.84
	Aug. 14	3.8	.26	5.19
	Sept. 17	4.9	.40	5.28
	Oct. 15	5.8	.32	5.42
	Nov. 17	6.9	.55	6.06
	Dec. 15	7.8	.47	6.00
	1921.			
	Jan. 15	8.8	.48	5.97
	Apr. 2	11.4	.52	6.01
	July 1	14.3	.62	6.69
	Oct. 1	17.3	.71	6.69
	1922.			
	Jan. 2	20.4	.76	7.00
BS-1 (25 pounds in metal drum)	1920.			
	Apr. 20	.....	0.35	5.12
	June 10	1.7	.24	4.72
	July 14	2.8	.20	4.53
	Aug. 14	3.8	.17	4.74
	Sept. 17	4.9	.24	4.49
	Oct. 15	5.8	.20	4.46
	Nov. 17	6.9	.22	4.61
	Dec. 15	7.8	.20	4.83
	1921.			
	Jan. 15	8.8	.21	5.00
	Apr. 2	11.4	.25	4.74
	July 1	14.3	.18	4.64
	Oct. 1	17.3	.19	4.43
	1922.			
	Jan. 2	20.4	.17	4.54
BS-2 (25 pounds in unlined sugar barrel)...	1920.			
	Apr. 20	.....	.30	5.19
	June 10	1.7	.37	5.30
	July 14	2.8	.35	5.44
	Aug. 14	3.8	.53	6.26
	Sept. 17	4.9	.67	6.10
	Oct. 15	5.8	.69	6.64
	Nov. 17	6.9	.79	6.96
	Dec. 15	7.8	.74	7.05
	1921.			
	Jan. 15	8.8	.77	7.06
	Apr. 2	11.4	.82	7.09
	July 1	14.3	.76	7.25
	Oct. 1	17.3	.78	6.90
	1922.			
	Jan. 2	20.4	.87	7.05
BS-3 (25 pounds in paper-lined sugar barrel)...	1920.			
	Apr. 20	.....	.32	5.12
	June 10	1.7	.46	5.61
	July 14	2.8	.60	6.06
	Aug. 14	3.8	.62	6.46
	Sept. 17	4.9	.75	6.61
	Oct. 15	5.8	.72	6.68
	Nov. 17	6.9	.77	6.95
	Dec. 15	7.8	.74	7.13
	1921.			
	Jan. 15	8.8	.77	7.15
	Apr. 2	11.4	.76	7.01
	July 1	14.3	.76	7.05
	Oct. 1	17.3	.76	7.20
	1922.			
	Jan. 2	20.4	.85	7.00
BS-4 (25 pounds in hardwood barrel).....	1920.			
	Apr. 20	.....	.29	4.87
	June 10	1.7	.27	4.59
	July 14	2.8	.25	4.56
	Aug. 14	3.8	.25	4.78
	Sept. 17	4.9	.25	4.32
	Oct. 15	5.8	.22	4.46
	Nov. 17	6.9	.30	5.16
	Dec. 15	7.8	.29	4.89
	1921.			
	Jan. 15	8.8	.32	5.05
	Apr. 2	11.4	.30	5.08
	July 1	14.3	.30	5.35
	Oct. 1	17.3	.59	6.66
	1922.			
	Jan. 2	20.4	.68	6.51

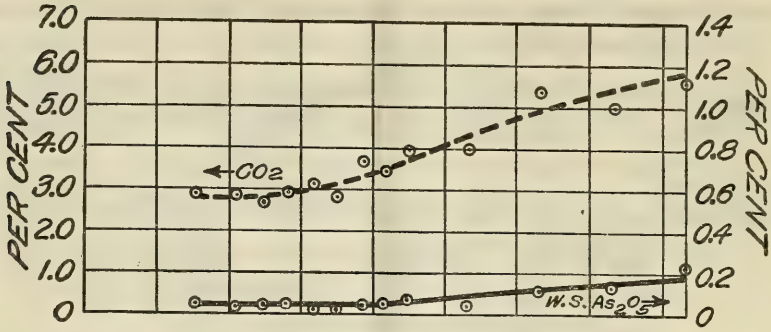

FIG. 9.—AS-6 (25 pounds in paper-lined veneer drum).

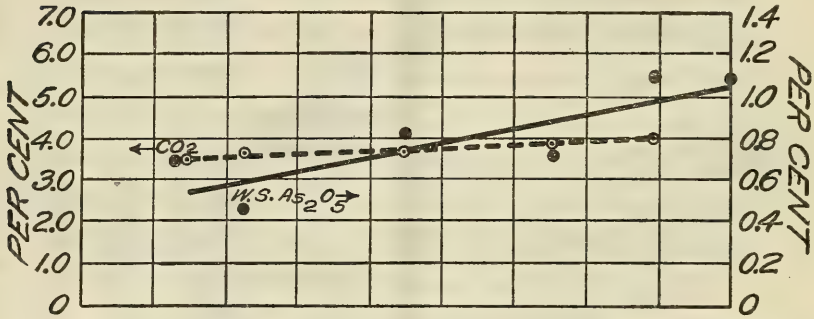

FIG. 10.—BW (100 pounds in paper-lined sugar barrel).

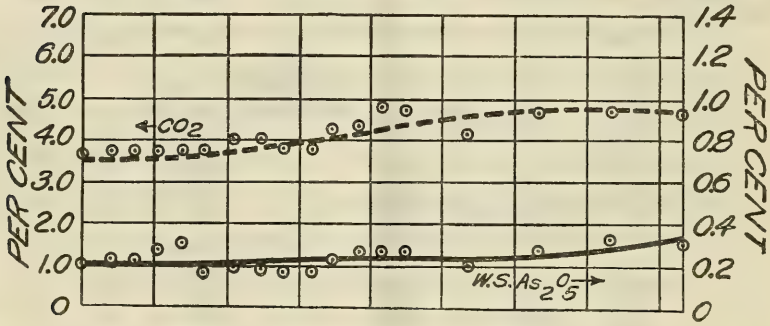

FIG. 11.—BT (100 pounds in hardwood barrel).

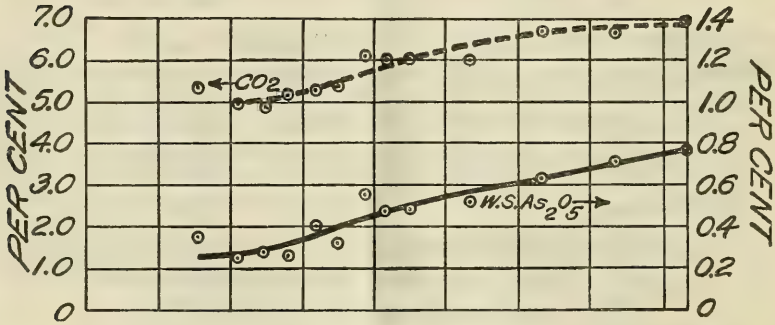

FIG. 12.—BS (50 pounds in paper-lined sugar barrel).

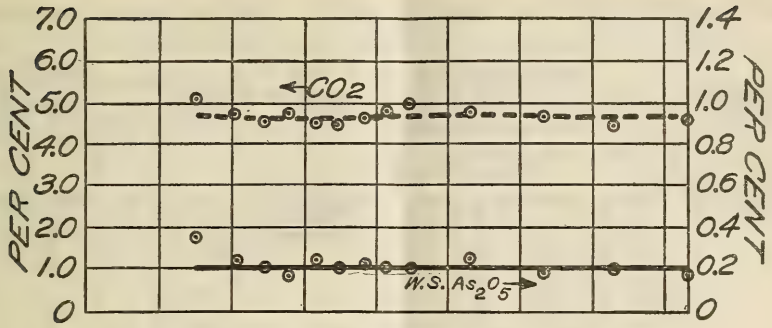

FIG. 13.—BS-1 (25 pounds in metal drum).

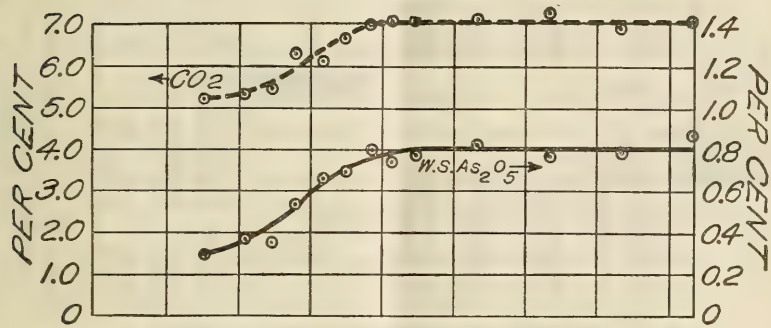

FIG. 14—BS-2 (25 pounds in unlined sugar barrel).

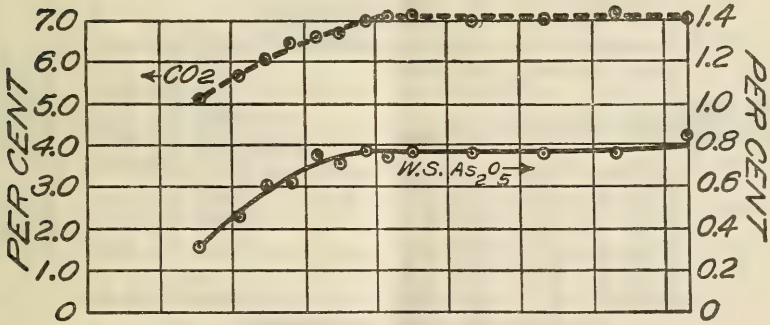

FIG. 15.—BS-3 (25 pounds in paper-lined sugar barrel).

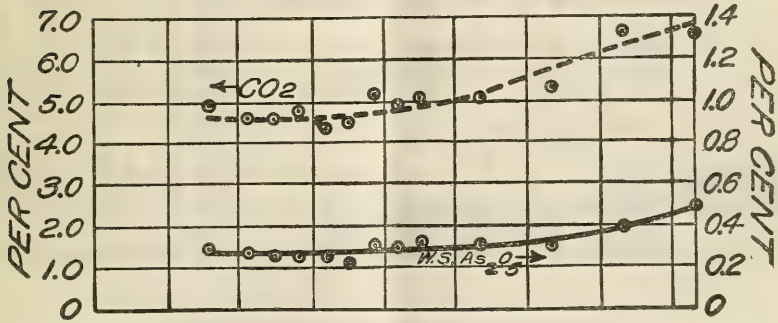

FIG. 16.—BS-4 (25 pounds in hardwood barrel).

TABLE 2.—*Effect of storage on chemical composition of calcium arsenate*—Continued.

Sample examined.	Date sampled.	Period of storage.	Water-soluble arsenic oxid (As_2O_5).	Carbon dioxid (CO_2).
BS-5 (25 pounds in unlined veneer drum)	1920.	*Mos.*	*Per ct.*	*Per ct.*
	Apr. 20	.....	0.29	4.80
	June 10	1.7	.35	5.15
	July 14	2.8	.30	5.08
	Aug. 14	3.8	.36	5.68
	Sept. 17	4.9	.50	5.80
	Oct. 15	5.8	.48	5.88
	Nov. 17	6.9	.69	.....
	Dec. 15	7.8	.67	6.63
	1921.			
	Jan. 15	8.8	.64	6.84
	Apr. 2	11.4	.74	7.11
	July 1	14.3	.73	7.23
	Oct. 1	17.3	.76	6.97
	1922.			
	Jan. 2	20.4	.94	7.07
BS-6 (25 pounds in paper-lined veneer drum)	1920.			
	Apr. 20	.....	.34	4.79
	June 10	1.7	.27	4.74
	July 14	2.8	.28	4.83
	Aug. 14	3.8	.25	5.28
	Sept. 17	4.9	.42	5.10
	Oct. 15	5.8	.32	5.11
	Nov. 17	6.9	.39	.....
	Dec. 15	7.8	.43	5.93
	1921.			
	Jan. 15	8.8	.55	6.23
	Apr. 2	11.4	.60	6.68
	July 1	14.3	.67	6.91
	Oct. 1	17.3	.72	6.93
	1922.			
	Jan. 2	20.4	.94	6.99
CT (100 pounds in paper-lined veneer drum)	1919.			
	Dec. 1	.....	.83	3.30
	1920.			
	Jan. 8	1.2	.76	3.29
	Feb. 6	2.2	.65	3.33
	Mar. 6	3.2	.56	3.45
	Apr. 7	4.2	.44	3.52
	May 4	5.1	.52	3.60
	June 10	6.3	.54	3.74
	July 14	7.4	.60	3.79
	Aug. 14	8.4	.69	3.90
	Sept. 17	9.5	.47	3.43
	Oct. 15	10.5	.52	3.63
	Nov. 17	11.5	.69	3.87
	Dec. 15	12.5	.63	4.19
	1921.			
	Jan. 15	13.5	.55	3.93
	Apr. 2	16.0	.43	5.97
	July 1	19.0	.62	3.98
	Oct. 1	22.0	.71	4.17
	1922.			
	Jan. 2	25.0	.70	4.40
CS (50 pounds in paper-lined veneer drum)	1920.			
	Apr. 20	.....	.15	4.47
	June 10	1.7	.18	4.42
	July 14	2.8	.18	4.76
	Aug. 14	3.8	.24	5.24
CS (50 pounds in paper-lined veneer drum) (continued.)	1920.	*Mos.*	*Per ct.*	*Per ct.*
	Sept. 17	4.9	0.36	4.89
	Oct. 15	5.8	.35	5.47
	Nov. 17	6.9	.40	5.78
	Dec. 15	7.8	.38	5.61
	1921.			
	Jan. 15	8.8	.41	5.78
	Apr. 2	11.4	.64	4.04
	July 1	14.3	.41	6.18
	Oct. 1	17.3	.45	5.90
	1922.			
	Jan. 2	20.4	.54	6.22
CS-1 (25 pounds in metal drum)	1920.			
	Apr. 20	.....	.15	4.68
	June 10	1.7	.14	4.33
	July 14	2.8	.14	4.22
	Aug. 14	3.8	.14	4.63
	Sept. 17	4.9	.17	4.37
	Oct. 15	5.8	.11	4.31
	Nov. 17	6.9	.12	4.47
	Dec. 15	7.8	.12	4.10
	1921.			
	Jan. 15	8.8	.13	4.60
	Apr. 2	11.4	.14	4.22
	July 1	14.3	.14	4.59
	Oct. 1	17.3	.14	4.38
	1922.			
	Jan. 2	20.4	.12	4.20
CS-2 (25 pounds in unlined sugar barrel)	1920.			
	Apr. 20	.....	.14	4.47
	June 10	1.7	.20	4.88
	July 14	2.8	.27	5.31
	Aug. 14	3.8	.36	5.22
	Sept. 17	4.9	.47	5.78
	Oct. 15	5.8	.43	5.73
	Nov. 17	6.9	.47	6.15
	Dec. 15	7.8	.47	6.00
	1921.			
	Jan. 15	8.8	.45	6.30
	Apr. 2	11.4	.42	6.17
	July 1	14.3	.44	6.25
	Oct. 1	17.3	.42	6.00
	1922.			
	Jan. 2	20.4	.54	6.20
CS-3 (25 pounds in paper-lined sugar barrel)	1920.			
	Apr. 20	.....	.15	4.40
	June 10	1.7	.16	4.47
	July 14	2.8	.17	4.86
	Aug. 14	3.8	.38	5.71
	Sept. 17	4.9	.50	5.98
	Oct. 15	5.8	.45	5.76
	Nov. 17	6.9	.46	6.06
	Dec. 15	7.8	.43	6.14
	1921.			
	Jan. 15	8.8	.46	6.04
	Apr. 2	11.4	.42	6.14
	July 1	14.3	.44	6.31
	Oct. 1	17.3	.44	6.31
	1922.			
	Jan. 2	20.4	.52	6.26

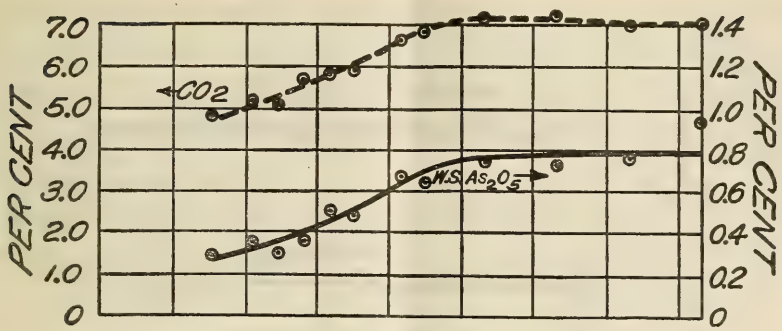

FIG. 17.—BS-5 (25 pounds in unlined veneer drum).

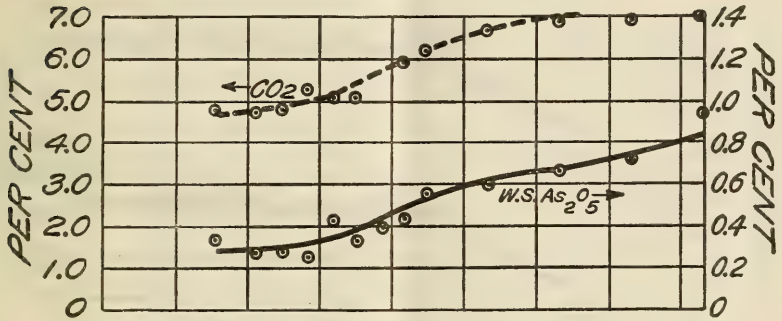

FIG. 18.—BS-6 (25 pounds in paper-lined veneer drum).

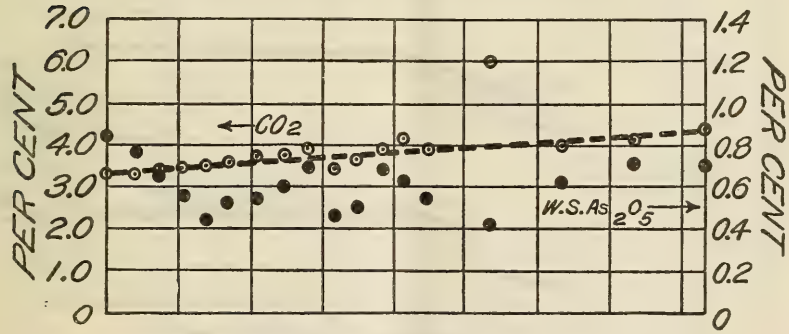

FIG. 19.—CT (100 pounds in paper-lined veneer drum).

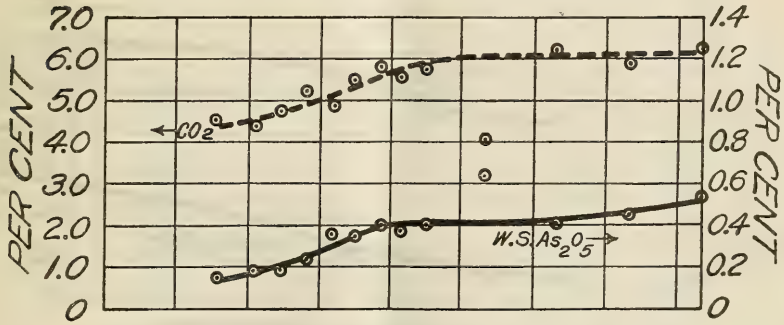

FIG. 20.—CS (50 pounds in paper-lined veneer drum).

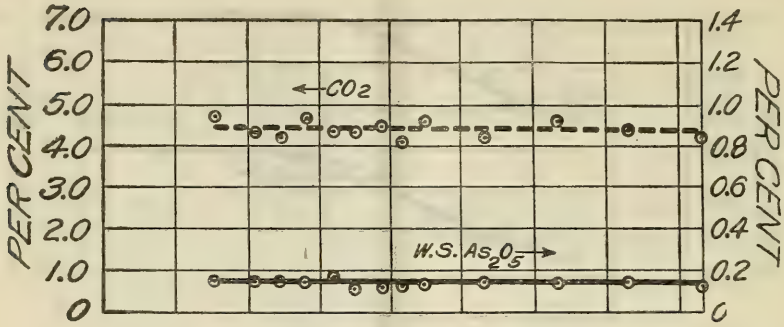

FIG. 21.—CS-1 (25 pounds in metal drum).

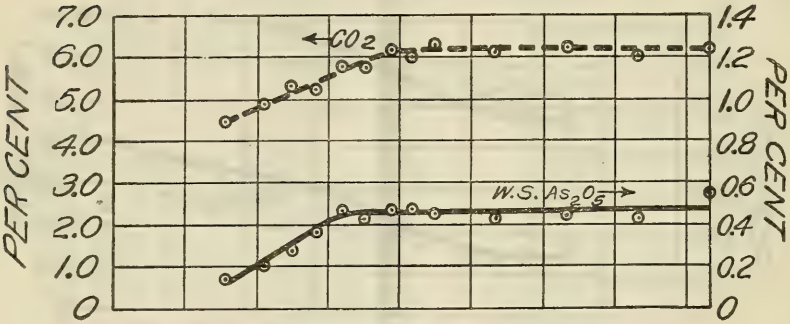

FIG. 22.—CS-2 (25 pounds in unlined sugar barrel).

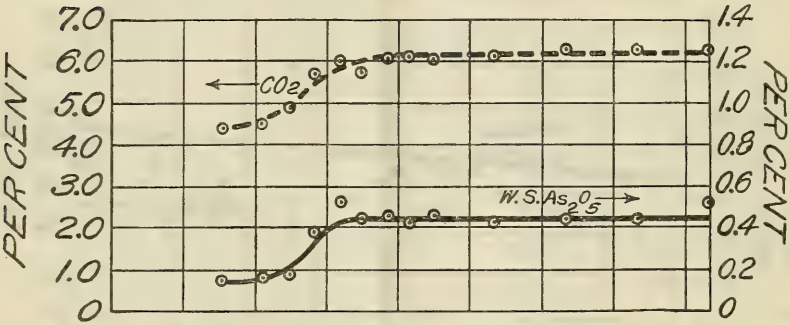

FIG. 23.—CS-3 (25 pounds in paper-lined sugar barrel).

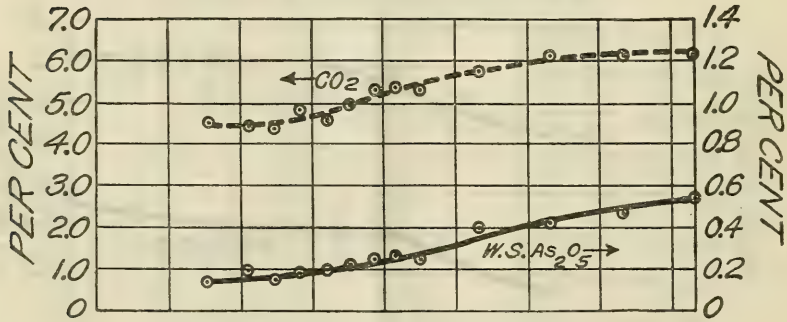

FIG. 24.—CS-4 (25 pounds in hardwood barrel).

TABLE 2.—*Effect of storage on chemical composition of calcium arsenate*—Continued.

Sample examined.	Date sampled.	Period of storage.	Water-soluble arsenic oxid (As_2O_5).	Carbon dioxid (CO_2).
CS-4 (25 pounds in hardwood barrel)	1920.	*Mos.*	*Per ct.*	*Per ct.*
	Apr. 20	.....	0.14	4.54
	June 10	1.7	.19	4.45
	July 14	2.8	.15	4.37
	Aug. 14	3.8	.18	4.84
	Sept. 17	4.9	.20	4.57
	Oct. 15	5.8	.22	4.92
	Nov. 17	6.9	.25	5.33
	Dec. 15	7.8	.27	5.36
	1921.			
	Jan. 15	8.8	.25	5.32
	Apr. 2	11.4	.40	5.75
	July 1	14.3	.42	6.09
	Oct. 1	17.3	.47	6.14
	1922.			
	Jan. 2	20.4	.54	6.08
CS-5 (25 pounds in unlined veneer drum)	1920.			
	Apr. 20	.....	.17	4.91
	June 10	1.7	.16	4.51
	July 14	2.8	.20	4.54
	Aug. 14	3.8	.17	4.94
	Sept. 17	4.9	.34	5.40
	Oct. 15	5.8	.37	5.67
	Nov. 17	6.9	.45	5.72
	Dec. 15	7.8	.46	6.28
	1921.			
	Jan. 15	8.8	.46	6.36
	Apr. 2	11.4	.46	6.06
	July 1	14.3	.45	6.24
	Oct. 1	17.3	.43	6.07
	1922.			
	Jan. 2	20.4	.51	6.91
CS-6 (25 pounds in paper-lined veneer drum)	1920.			
	Apr. 20	.....	.15	4.80
	June 10	1.7	.16	4.24
	July 14	2.8	.16	4.24
	Aug. 14	3.8	.17	4.62
	Sept. 17	4.9	.20	4.39
	Oct. 15	5.8	.13	4.56
	Nov. 17	6.9	.24	5.06
	Dec. 15	7.8	.20	5.44
	1921.			
	Jan. 15	8.8	.25	5.30
	Apr. 2	11.4	.20	5.29
	July 1	14.3	.39	5.59
	Oct. 1	17.3	.48	5.91
	1922.			
	Jan. 2	20.4	.54	5.83
FT (100 pounds in unlined veneer drum)	1920.			
	Apr. 7	.....	.00	1.40
	May 4	.9	.01	1.44
	June 10	2.1	.03	1.62
	July 14	3.2	.03	1.65
	Aug. 14	4.2	.03	1.66
	Sept. 17	5.3	.02	1.83
	Oct. 15	6.3	.02	1.94
	Nov. 17	7.3	.02	2.79
	Dec. 15	8.3	.02	2.38
	1921.			
	Jan. 15	9.3	.02	2.41
	Apr. 2	11.8	.02	2.52
	July 1	14.7	.05	3.97
	Oct. 1	17.8	.04	3.78
	1922.			
	Jan. 2	20.8	.09	3.09
FS (75 pounds in paper-lined veneer drum)	1920.	*Mos.*	*Per ct.*	*Per ct.*
	Apr. 20	.....	0.04	1.91
	June 10	1.7	.06	1.85
	July 14	2.8	.06	2.94
	Aug. 14	3.8	.07	3.62
	Sept. 17	4.9	.07	2.75
	Oct. 15	5.8	.05	3.36
	Nov. 17	6.9	.10	4.81
	Dec. 15	7.8	.07	4.30
	1921.			
	Jan. 15	8.8	.10	4.19
	Apr. 2	11.4	.11	4.26
	July 1	14.3	.22	5.54
	Oct. 1	17.3	.26	5.28
	1922.			
	Jan. 2	20.4	.36	5.75
FS-1 (25 pounds in metal drum)	1920.			
	Apr. 20	.....	.05	2.09
	June 10	1.7	.05	1.72
	July 14	2.8	.03	1.64
	Aug. 14	3.8	.05	1.74
	Sept. 17	4.9	.05	1.67
	Oct. 15	5.8	.05	1.88
	Nov. 17	6.9	.05	1.70
	Dec. 15	7.8	.05	2.16
	1921.			
	Jan. 15	8.8	.05	1.79
	Apr. 2	11.4	.03	1.98
	July 1	14.3	.05	2.36
	Oct. 1	17.3	.05	1.81
	1922.			
	Jan. 2	20.4	.05	1.88
FS-3 (25 pounds in paper-lined sugar barrel)	1920.			
	Apr. 20	.....	.06	2.01
	June 10	1.7	.08	2.30
	July 14	2.8	.05	3.12
	Aug. 14	3.8	.07	3.49
	Sept. 17	4.9	.09	3.81
	Oct. 15	5.8	.10	4.53
	Nov. 17	6.9	.15	5.32
	Dec. 15	7.8	.15	5.62
	1921.			
	Jan. 15	8.8	.25	5.70
	Apr. 2	11.4	.32	5.61
	July 1	14.3	.34	5.74
	Oct. 1	17.3	.32	5.68
	1922.			
	Jan. 2	20.4	.41	5.62
FS-4 (25 pounds in hardwood barrel)	1920.			
	Apr. 20	.....	.05	2.05
	June 10	1.7	.05	1.87
	July 14	2.8	.05	1.88
	Aug. 14	3.8	.07	2.00
	Sept. 17	4.9	.06	2.05
	Oct. 15	5.8	.05	2.04
	Nov. 17	6.9	.08	2.06
	Dec. 15	7.8	.05	2.94
	1921.			
	Jan. 15	8.8	.06	2.71
	Apr. 2	11.4	.09	2.38
	July 1	14.3	.05	2.72
	Oct. 1	17.3	.07	3.04
	1922.			
	Jan. 2	20.4	.07	3.38

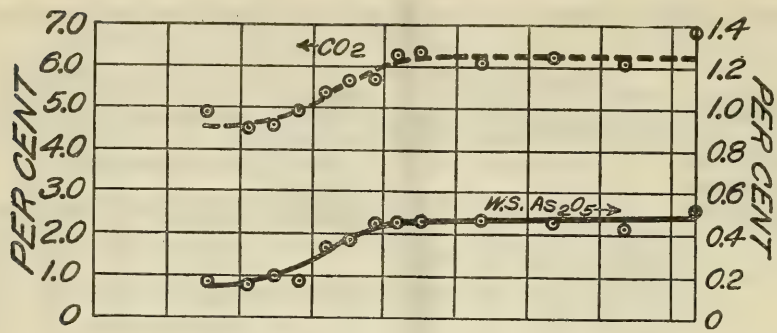

FIG. 25.—CS-5 (25 pounds in unlined veneer drum).

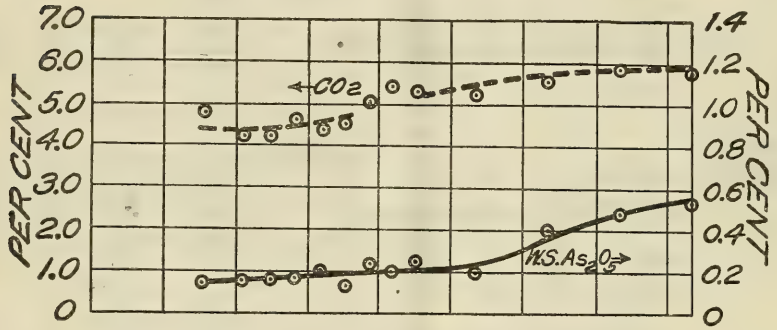

FIG. 26.—CS-6 (25 pounds in paper-lined veneer drum).

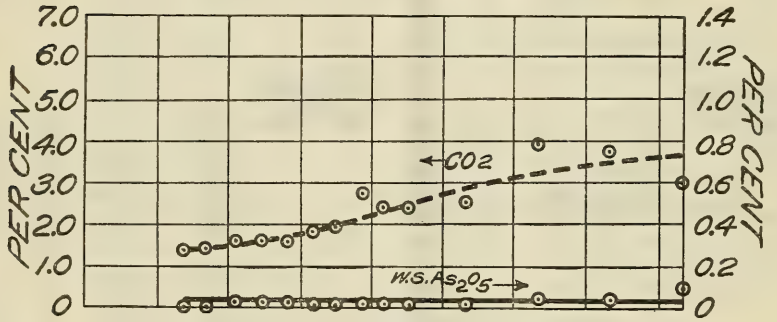

FIG. 27.—FT (100 pounds in unlined veneer drum).

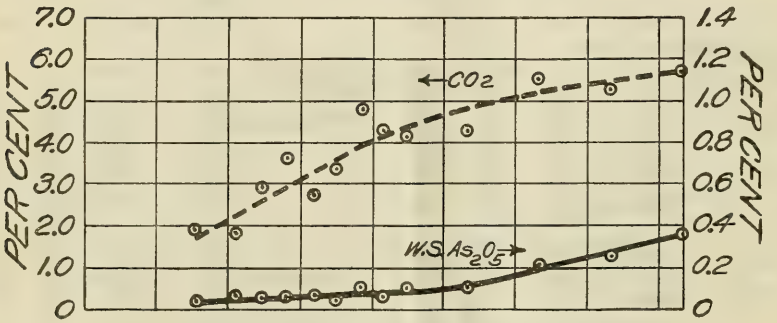

FIG. 28.—FS (75 pounds in paper-lined veneer drum).

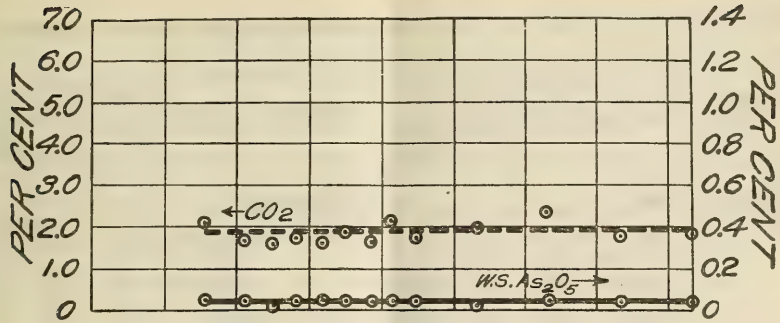

FIG. 29.—FS-1 (25 pounds in metal drum).

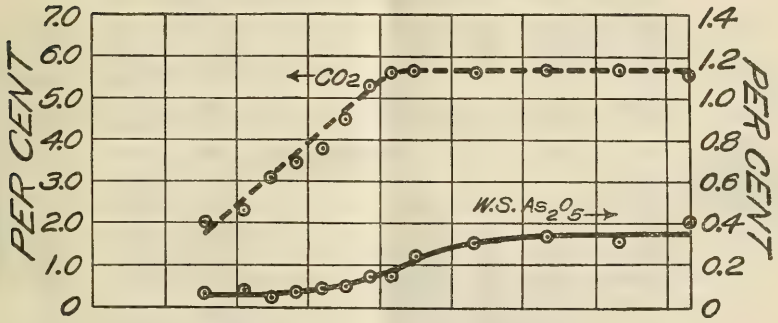

FIG. 30.—FS-3 (25 pounds in paper-lined sugar barrel).

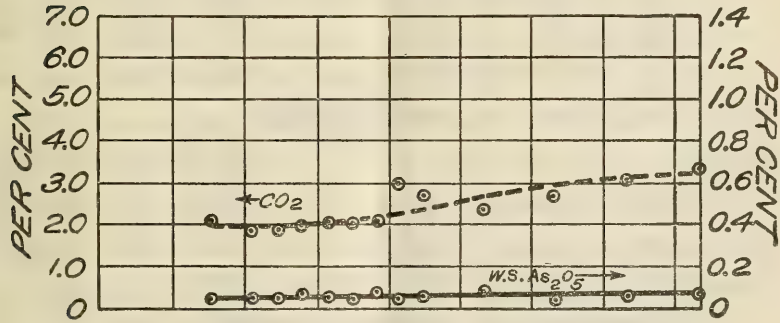

FIG. 31.—FS-4 (25 pounds in hardwood barrel).

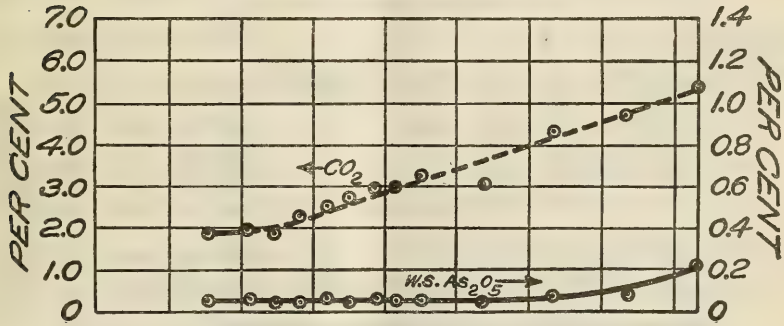

FIG. 32.—FS-5 (25 pounds in unlined veneer drum).

TABLE 2.—*Effect of storage on chemical composition of calcium arsenate*—Continued.

Sample examined.	Date sampled.	Period of storage	Water-soluble arsenic oxid (As_2O_5).	Carbon dioxid (CO_2).
FS-5 (25 pounds in unlined veneer drum)	1920.	*Mos.*	*Per ct.*	*Per ct.*
	Apr. 20	.....	0.05	1.90
	June 10	1.7	.06	1.96
	July 14	2.8	.05	1.88
	Aug. 14	3.8	.05	2.26
	Sept. 17	4.9	.06	2.53
	Oct. 15	5.8	.05	2.68
	Nov. 17	6.9	.07	2.95
	Dec. 15	7.8	.06	2.98
	1921.			
	Jan. 15	8.8	.06	3.28
	Apr. 2	11.4	.05	3.08
	July 1	14.3	.08	4.36
	Oct. 1	17.3	.09	4.77
	1922.			
	Jan. 2	20.4	.22	5.38
FS-6 (25 pounds in paper-lined veneer drum)	1920.			
	Apr. 20	.....	.06	1.93
	June 10	1.7	.05	2.16
	July 14	2.8	.05	2.34
	Aug. 14	3.8	.05	2.35
	Sept. 17	4.9	.06	2.30
	Oct. 15	5.8	.05	2.62
	Nov. 17	6.9	.07	3.48
	Dec. 15	7.8	.07	3.79
	1921.			
	Jan. 15	8.8	.07	4.06
	Apr. 2	11.4	.08	3.80
	July 1	14.3	.12	5.17
	Oct. 1	17.3	.33	5.51
	1922.			
	Jan. 2	20.4	.39	5.23
HW (50 pounds in hardwood barrel)	1920.			
	Apr. 12	.....	.11	.87
	June 23	2.4	.08	.90
	1921.			
	Jan. 14	9.1	.09	.93
	July 20	15.3	.07	1.07
	Nov. 25	19.4	.07	.97
	1922.			
	Mar. 1	22.6	.....	.....
HT (100 pounds in hardwood barrel)	1920.			
	Apr. 20	.....	.10	1.33
	May 4	.5	.07	.84
	June 10	1.7	.06	.86
	July 14	2.8	.04	.97
	Aug. 14	3.8	.02	.99
	Sept. 17	4.9	.02	.91
	Oct. 15	5.8	.02	1.25
	Nov. 17	6.9	.02	1.52
	Dec. 15	7.8	.02	2.35
	1921.			
	Jan. 15	8.8	.02	1.94
	Apr. 2	11.4	.02	2.92
	July 1	14.3	.05	2.87
	Oct. 1	17.3	.04	2.77
	1922.			
	Jan. 2	20.4	.12	3.72
HS (100 pounds in hardwood barrel)	1920.	*Per ct.*	*Per ct.*	*Per ct.*
	Apr. 20	.....	0.10	1.07
	June 10	1.7	.05	.95
	July 14	2.8	.04	.88
	Aug. 14	3.8	.02	.98
	Sept. 17	4.9	.02	.85
	Oct. 15	5.8	.02	1.02
	Nov. 17	6.9	.02	1.04
	Dec. 15	7.8	.04	1.28
	1921.			
	Jan. 15	8.8	.02	.94
	Apr. 2	11.4	.02	1.48
	July 1	14.3	.02	1.54
	Oct. 1	17.3	.02	1.51
	1922.			
	Jan. 2	20.4	.07	1.69
HS-1 (25 pounds in metal drum)	1920.			
	Apr. 20	.....	.11	1.25
	June 10	1.7	.04	1.00
	July 14	2.8	.04	.97
	Aug. 14	3.8	.02	.92
	Sept. 17	4.9	.02	.93
	Oct. 15	5.8	.02	.95
	Nov. 17	6.9	.02	1.22
	Dec. 15	7.8	.02	1.18
	1921.			
	Jan. 15	8.8	.02	.98
	Apr. 2	11.4	.02	.97
	July 1	14.3	.02	.93
	Oct. 1	17.3	.02	1.01
	1922.			
	Jan. 2	20.4	.05	1.02
HS-4 (25 pounds in hardwood barrel)	1920.			
	Apr. 20	.....	.11	1.08
	June 10	1.7	.05	1.06
	July 14	2.8	.05	1.11
	Aug. 14	3.8	.05	1.20
	Sept. 17	4.9	.02	1.07
	Oct. 15	5.8	.02	1.06
	Nov. 17	6.9	.02	1.52
	Dec. 15	7.8	.02	1.66
	1921.			
	Jan. 15	8.8	.02	1.34
	Apr. 2	11.4	.02	1.38
	July 1	14.3	.02	2.52
	Oct. 1	17.3	.02	1.88
	1922.			
	Jan. 2	20.4	.07	1.81
HS-6 (25 pounds in paper-lined veneer drum)	1920.			
	Apr. 20	.....	.11	1.05
	June 10	1.7	.05	1.02
	July 14	2.8	.07	1.15
	Aug. 14	3.8	.05	1.10
	Sept. 17	4.9	.02	1.22
	Oct. 15	5.8	.05	1.28
	Nov. 17	6.9	.02	1.48
	Dec. 15	7.8	.02	2.24
	1921.			
	Jan. 15	8.8	.02	1.87
	Apr. 2	11.4	.02	1.78
	July 1	14.3	.04	2.56
	Oct. 1	17.3	.05	3.09
	1922.			
	Jan. 2	20.4	.07	3.15

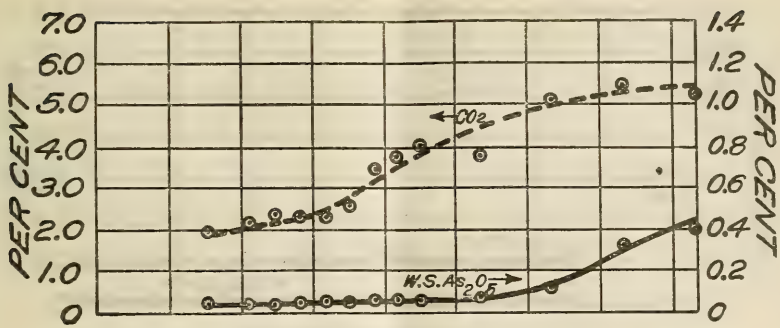

FIG. 33.—FS-6 (25 pounds in paper-lined veneer drum).

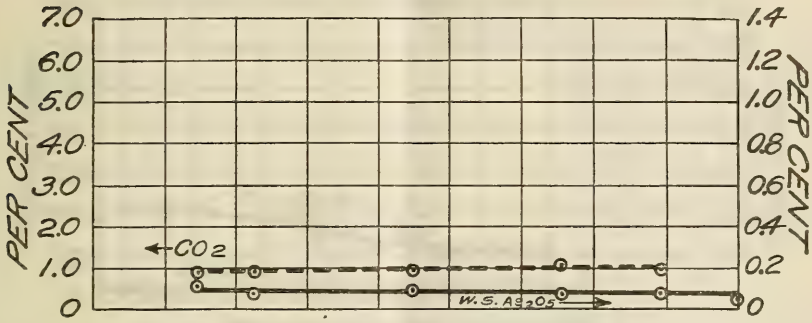

FIG. 34.—HW (50 pounds in hardwood barrel).

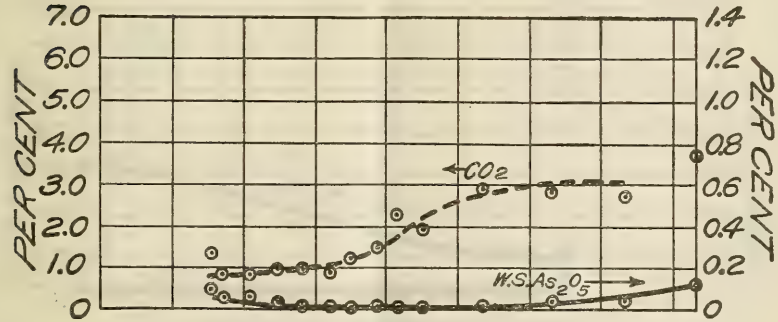

FIG. 35.—HT (100 pounds in hardwood barrel).

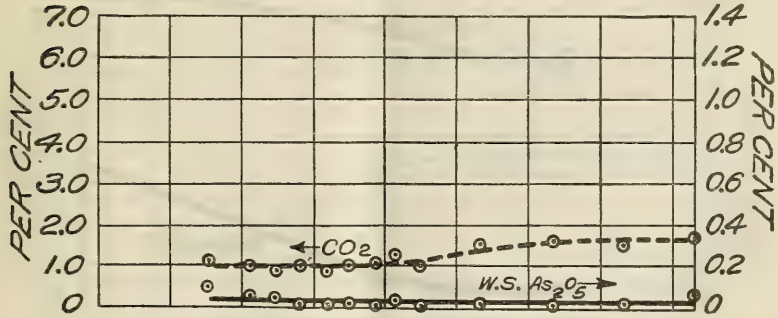

FIG. 36.—HS (100 pounds in hardwood barrel).

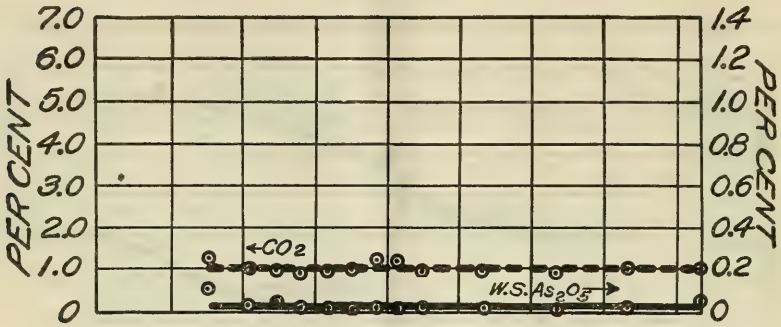

FIG. 37.—HS-1 (25 pounds in metal drum).

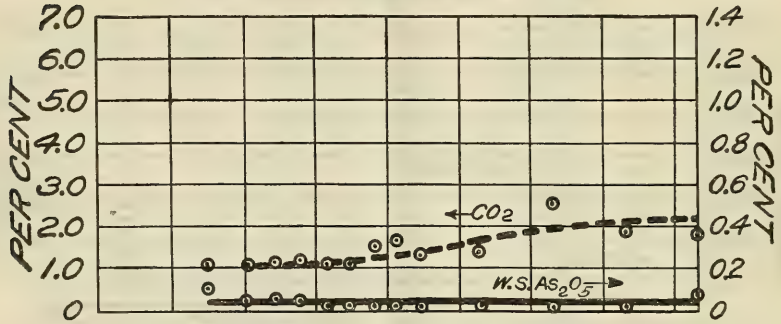

FIG. 38.—HS-4 (25 pounds in hardwood barrel).

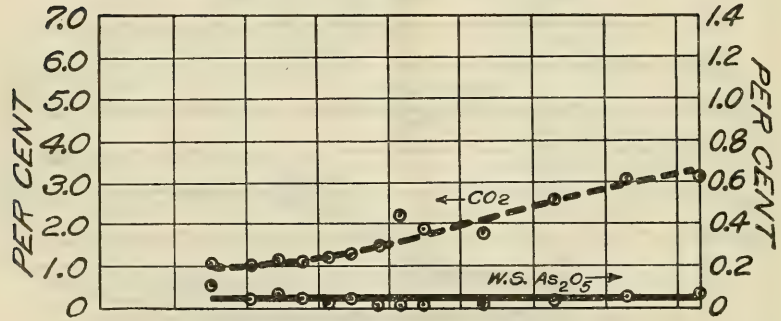

FIG. 39.—HS-6 (25 pounds in paper-lined veneer drum).

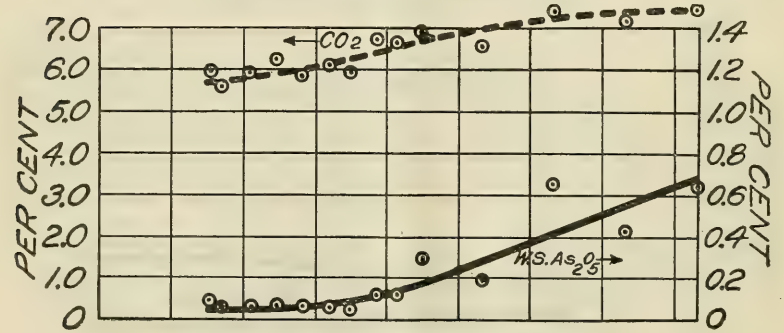

FIG. 40.—IT (100 pounds in paper-lined sugar barrel).

TABLE 2.—*Effect of storage on chemical composition of calcium arsenate*—Continued.

Sample examined.	Date sampled.	Period of storage.	Water-soluble arsenic oxid (As_2O_5).	Carbon dioxid (CO_2).
IT (100 pounds in paper-lined sugar barrel)...	1920.	*Mos.*	*Per ct.*	*Per ct.*
	Apr. 20	.....	0.08	5.95
	May 4	0.5	.07	5.61
	June 10	1.7	.06	5.92
	July 14	2.8	.07	6.25
	Aug. 14	3.8	.07	5.85
	Sept. 17	4.9	.06	6.08
	Oct. 15	5.8	.05	5.94
	Nov. 17	6.9	.12	6.76
	Dec. 15	7.8	.12	6.69
	1921.			
	Jan. 15	8.8	.28	6.90
	Apr. 2	11.4	.18	6.60
	July 1	14.3	.65	7.43
	Oct. 1	17.3	.42	7.18
	1922.			
	Jan. 2	20.4	.64	7.44
IS (100 pounds in paper-lined sugar barrel)...	1920.			
	Apr. 20	.....	.39	5.69
	June 10	1.7	.38	6.12
	July 14	2.8	.37	5.70
	Aug. 14	3.8	.50	5.79
	Sept. 17	4.9	.55	6.23
	Oct. 15	5.8	.69	6.08
	Nov. 17	6.9	.73	6.16
	Dec. 15	7.8	.68	6.39
	1921.			
	Jan. 15	8.8	.79	6.46
	Apr. 2	11.4	.77	6.49
	July 1	14.3	.85	6.26
	Oct. 1	17.3	.83	6.42
	1222.			
	Jan. 2	20.4	88	6.89
IS-1 (25 pounds in metal drum)	1920.			
	Apr. 20	.....	.36	6.09
	June 10	1.7	.35	6.06
	July 14	2.8	.32	5.58
	Aug. 14	3.8	.36	5.82
	Sept. 17	4.9	.43	5.85
	Oct. 15	5.8	.37	5.75
	Nov. 17	6.9	.37	5.86
	Dec. 15	7.8	.40	5.24
	1921.			
	Jan. 15	8.8	.36	6.00
	Apr. 2	11.4	.35	6.01
	July 1	14.3	.30	6.11
	Oct. 1	17.3	.36	6.03
	1922.			
	Jan. 2	20.4	.54	5.78
IS-3 (25 pounds in paper-lined sugar barrel)...	1920.			
	Apr. 20	.....	.31	5.51
	June 10	1.7	.54	6.09
	July 14	2.8	.77	6.58
	Aug. 14	3.8	.92	6.55
IS-3 (25 pounds in paper-lined sugar barrel) (con.).	1920.	*Mos.*	*Per ct.*	*Per ct.*
	Sept. 17	4.9	0.93	6.59
	Oct. 15	5.8	.93	6.20
	Nov. 17	6.9	.92	6.37
	Dec. 15	7.8	.96	6.61
	1921.			
	Jan. 15	8.8	.91	6.64
	Apr. 2	11.4	.88	6.46
	July 1	14.3	.90	6.41
	Oct. 1	17.3	.94	6.40
	1922.			
	Jan. 2	20.4	.94	7.10
IS-4 (25 pounds in hardwood barrel).....	1920.			
	Apr. 20	.....	.41	5.86
	June 10	1.7	.32	6.12
	July 14	2.8	.32	5.90
	Aug. 14	3.8	.39	5.83
	Sept. 17	4.9	.51	5.65
	Oct. 15	5.8	.49	5.71
	Nov. 17	6.9	.55	6.00
	Dec. 15	7.8	.71	5.98
	1921.			
	Jan. 15	8.8	.63	6.40
	Apr. 2	11.4	.70	6.23
	July 1	14.3	.78	6.27
	Oct. 1	17.3	.94	6.43
	1922.			
	Jan. 2	20.4	.94	6.30
IS-6 (25 pounds in paper-lined veneer drum)..	1920.			
	Apr. 20	.....	.37	5.74
	June 10	1.7	.42	6.36
	July 14	2.8	.62	6.11
	Aug. 14	3.8	.79	6.25
	Sept. 17	4.9	.97	6.45
	Oct. 15	5.8	.99	6.30
	Nov. 17	6.9	1.00	6.54
	Dec. 15	7.8	.96	6.64
	1921.			
	Jan. 15	8.8	.97	6.78
	Apr. 2	11.4	.92	6.32
	July 1	14.3	.90	6.42
	Oct. 1	17.3	.99	6.61
	1922.			
	Jan. 2	20.4	.97	6.27
JW (50 pounds in metal drum)	1920.			
	Apr. 12	.....	.30	2.69
	June 23	2.4	.24	2.90
	1921.			
	Jan. 14	9.1	.30	2.77
	July 20	15.3	.28	2.64
	Nov. 25	19.4	.26	2.76
	1922.			
	Mar. 1	22.6	.....	.....

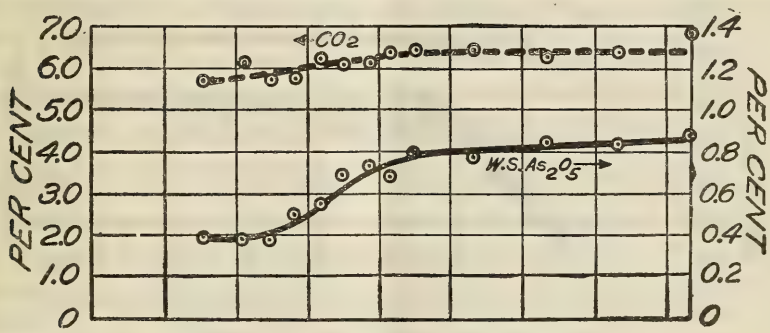

FIG. 41.—IS (100 pounds in paper-lined sugar barrel).

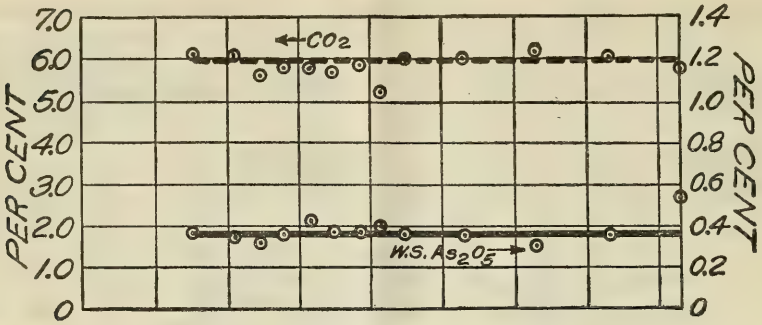

FIG. 42.—IS-1 (25 pounds in metal drum).

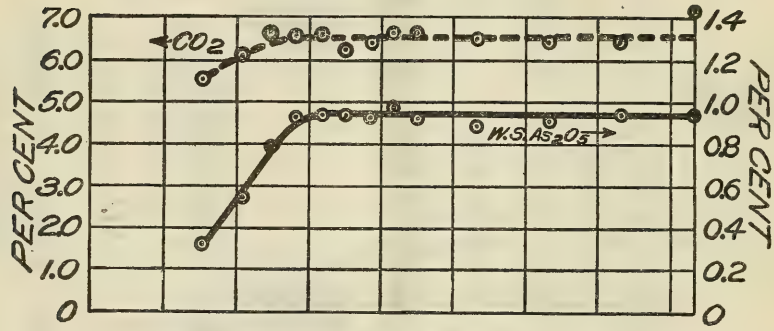

FIG. 43.—IS-3 (25 pounds in paper-lined sugar barrel).

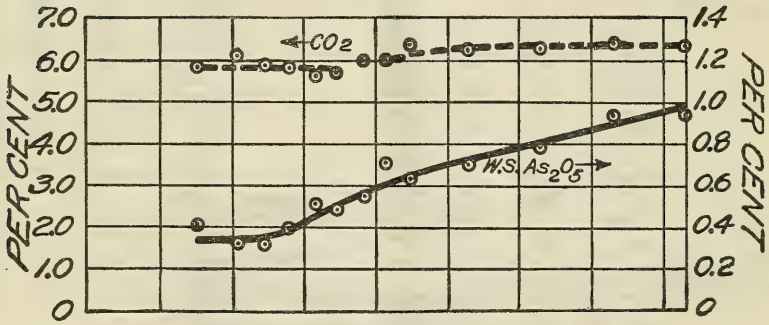

FIG. 44.—IS-4 (25 pounds in hardwood barrel).

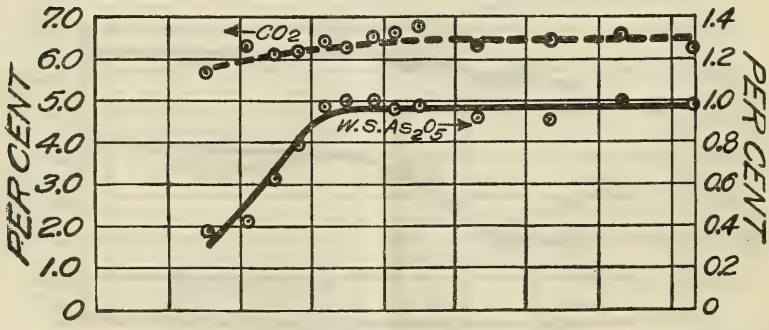

FIG. 45.—IS-6 (25 pounds in paper-lined veneer drum).

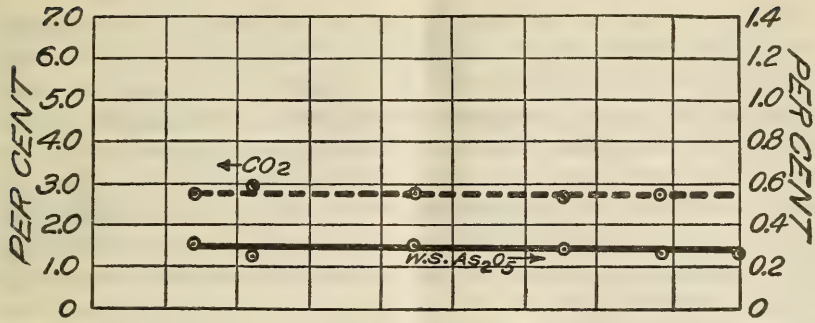

FIG. 46.—JW (50 pounds in metal drum).

DISCUSSION.

The arsenic oxid in water-soluble form and the carbon dioxid increased in all of the samples except those packed in the tightest containers. The close relationship between the increase in water-soluble arsenic and in carbon dioxid is plainly shown by the parallelism between the carbon dioxid and arsenic oxid curves for most of the samples.

In some cases the carbon dioxid content increases from the beginning, but the quantity of water-soluble arsenic oxid begins to increase only after some time has elapsed. This is undoubtedly due to the fact that a certain quantity of free lime is necessary to repress the "solubility" (really decomposition) of the calcium arsenate, and any free lime in excess of this amount can carbonate without affecting the soluble arsenic oxid. Once this limit is passed, however, decomposition begins. Many of the curves also show a limiting value for each of the two changes, these limits being reached at approximately the same time. This is well shown in the case of subsamples stored in sugar barrels, the most open containers, the greater number of which reached equilibrium in from six to nine months. It might naturally be assumed that this corresponds to the complete carbonation of the free lime in the samples, the final mixture being essentially tricalcium arsenate and calcium carbonate. Calculating the limiting carbon dioxid values to their equivalent calcium oxid values and subtracting these from the total calcium oxid, however, leaves calcium oxid remaining in amounts from 0.2 to 4.8 per cent in excess of the quantity necessary to form tricalcium arsenate with the total arsenic oxid of the sample. Pure tricalcium arsenate octahydrate [$Ca_3(AsO_4)_2.8H_2O$], containing 42 per cent total arsenic oxid, gave about 3 per cent water-soluble arsenic oxid, while the completely carbonated commercial samples exceeded 1 per cent in only one case (*B W*), which seems to argue against this being the only calcium arsenate in commercial samples. Further work will be necessary before the question of the presence of basic arsenates can be definitely settled.

There is a marked difference in the rate of change in the samples attributable to the types of containers. The samples stored in the metal drums showed practically no change. The change in those stored in the other containers varied from a very slight one, in the case of the tightest hardwood barrels, to a marked one in the case of the more open containers, such as sugar barrels. For the hardwood barrels the average increase in water-soluble arsenic oxid after 12 months was 0.06 per cent (maximum, 0.31 per cent) and in carbon dioxid, 0.85 per cent; at the end of 20 months, the average increase was 0.15 per cent in soluble arsenic oxid (maximum, 0.53 per cent) and 1.40 per cent in carbon dioxid. The samples stored in the paper-lined and unlined veneer drums showed little difference. At the end of 12 months the average increase in soluble arsenic oxid was 0.15 per cent (maximum, 0.55 per cent) and in carbon dioxid 1.38 per cent. After 20 months the average increase in soluble arsenic oxid was 0.30 per cent (maximum, 0.65 per cent) and in carbon dioxid 2.21 per cent. In the lined and unlined sugar barrels the average increase in soluble arsenic oxid after 12 months was 0.31 per cent (maximum, 0.57 per cent) and in carbon dioxid 1.72 per cent. After 20 months the soluble arsenic oxid increase averaged 0.45 per cent (maximum, 0.63 per cent) and the carbon dioxid increase averaged 2.01 per cent.

The average results showing the behavior of the material stored in the different containers are given in Table 3 and Figures 47, 48, 49, and 50. Each curve represents the average of the products of different manufacturers contained in packages of the same type. Four types of containers, metal drum (1), paper-lined sugar barrel (3), hardwood barrel (4), and paper-lined veneer drum (6), are represented under the six brands[8] included in the subdivision tests, and all of these (23 subdivisions) were subsampled on exactly the same dates. Each type of container is treated separately in order to bring out the parallelism between the carbon dioxid and water-soluble arsenic changes, and two graphs, showing all four curves for carbon dioxid and for arsenic oxid, respectively, are presented in Figures 51 and 52.

[8] Only five brands are represented in the case of the paper-lined barrels.

TABLE 3.—*Effect of type of container on chemical composition of calcium arsenate during storage.*

Type of container.	Date sampled.	Period of storage.	Water-soluble arsenic oxid (As_2O_5)	Carbon dioxid (CO_2).	Type of container.	Date sampled.	Period of storage.	Water-soluble arsenic oxid (As_2O_5)	Carbon dioxid (CO_2).
Metal drums (samples AS-1, BS-1, CS-1, FS-1, HS-1, IS-1)	1920.	*Mos.*	*Per ct.*	*Per ct.*	Hardwood barrels (samples AS-4, BS-4, CS-4, FS-4, HS-4, IS-4)	1920.	*Mos.*	*Per ct.*	*Per ct.*
	Apr. 20	.....	0.18	3.69		Apr. 20	.....	0.17	3.54
	June 10	1.7	.14	3.45		June 10	1.7	.16	3.54
	July 14	2.8	.13	3.26		July 14	2.8	.15	3.67
	Aug. 14	3.8	.13	3.39		Aug. 14	3.8	.17	3.91
	Sept. 17	4.9	.15	3.30		Sept. 17	4.9	.22	3.91
	Oct. 15	5.8	.13	3.33		Oct. 15	5.8	.23	4.06
	Nov. 17	6.9	.13	3.40		Nov. 17	6.9	.26	4.37
	Dec. 15	7.8	.14	3.38		Dec. 15	7.8	.29	4.51
	1921.					1921.			
	Jan. 15	8.8	.14	3.53		Jan. 15	8.8	.27	4.47
	Apr. 2	11.4	.14	3.45		Apr. 2	11.4	.31	4.49
	July 1	14.3	.13	3.54		July 1	14.3	.32	4.86
	Oct. 1	17.3	.14	3.36		Oct. 1	17.3	.42	5.06
	1922.					1922.			
	Jan. 2	20.4	.16	3.33		Jan. 2	20.4	.46	5.09
Paper-lined sugar barrels (samples AS-3, BS-3, CS-3, FS-3, IS-3)	1920.				Paper-lined veneer drums (samples AS-6, BS-6, CS-6, FS-6, HS-6, IS-6)	1920.			
	Apr. 20	.....	.18	4.00		Apr. 20	.....	.16	3.53
	June 10	1.7	.26	4.41		June 10	1.7	.16	3.56
	July 14	2.8	.32	4.77		July 14	2.8	.20	3.56
	Aug. 14	3.8	.41	5.29		Aug. 14	3.8	.23	3.74
	Sept. 17	4.9	.47	5.50		Sept. 17	4.9	.28	3.81
	Oct. 15	5.8	.45	5.46		Oct. 15	5.8	.26	3.73
	Nov. 17	6.9	.50	6.09		Nov. 17	6.9	.29	4.29
	Dec. 15	7.8	.49	6.27		Dec. 15	7.8	.29	4.58
	1921.					1921.			
	Jan. 15	8.8	.52	6.27		Jan. 15	8.8	.32	4.69
	Apr. 2	11.4	.55	6.25		Apr. 2	11.4	.31	4.65
	July 1	14.3	.55	6.31		July 1	14.3	.37	5.34
	Oct. 1	17.3	.55	6.34		Oct. 1	17.3	.45	5.51
	1922.					1922.			
	Jan. 2	20.4	.60	6.45		Jan. 2	20.4	.52	5.51

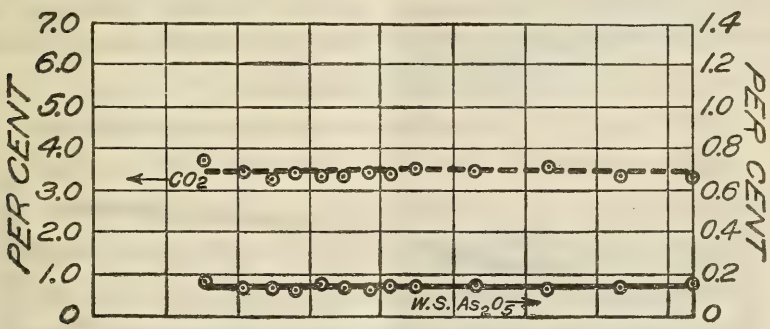

FIG. 47.—Average results with AS-1, BS-1, CS-1, FS-1, HS-1, IS-1 (metal drums).

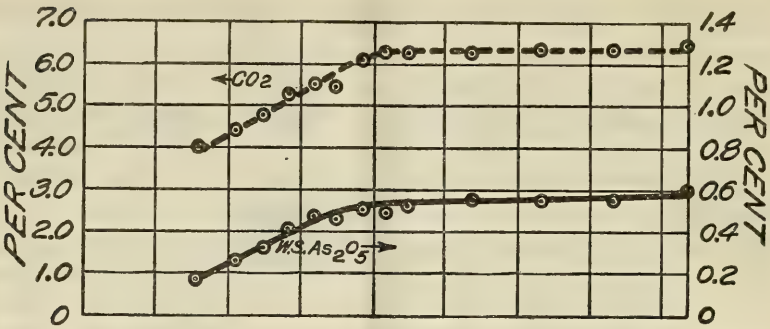

FIG. 48.—Average results with AS-3, BS-3, CS-3, FS-3, IS-3 (paper-lined sugar barrels).

All of the sugar barrels were in bad condition at the end of the test because of handling incident to sampling. The results of the tests show the unfitness of this type of container as a package for commercial purposes.

It is plainly shown that the containers are rated in the same order by both the carbon dioxid and the water-soluble arsenic oxid results. The metal drums show no change and the sugar barrels show the most rapid change, the other two being intermediate. Little difference between the lined and unlined containers of the same type is observed. The calcium arsenate stored in the sugar barrels apparently reached equilibrium in most cases in approximately eight months. No seasonal variation in the rate of change is apparent.

Very little information concerning the effect of locality was obtained. Strictly comparable results were possible only with samples *AW* and *AT*, and samples *HW* and *HT*. In both cases the rate of absorption of carbon dioxid was higher at Tallulah than at Washington. The authors are not in a position to state whether or not this was due to a higher carbon dioxid content in the air at Tallulah or to some other condition.

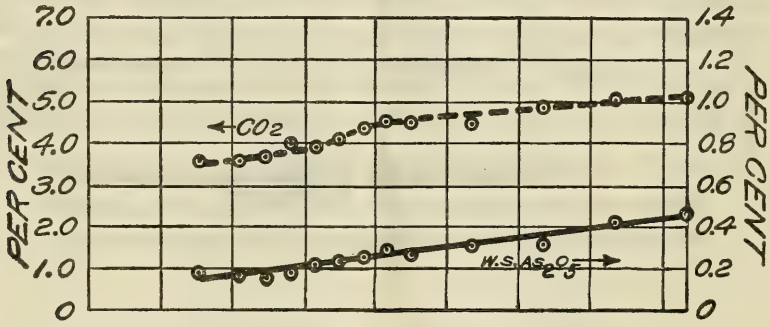

FIG. 49.—Average results with AS-4, BS-4, CS-4, FS-4, HS-4, IS-4 (hardwood barrels).

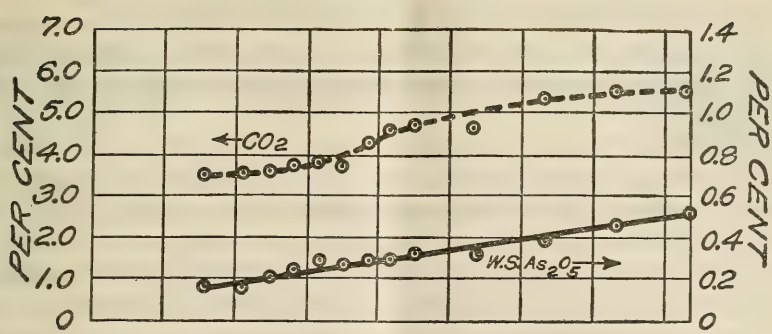

FIG. 50.—Average results with AS-6, BS-6, CS-6, FS-6, HS-6, IS-6 (paper-lined veneer drums).

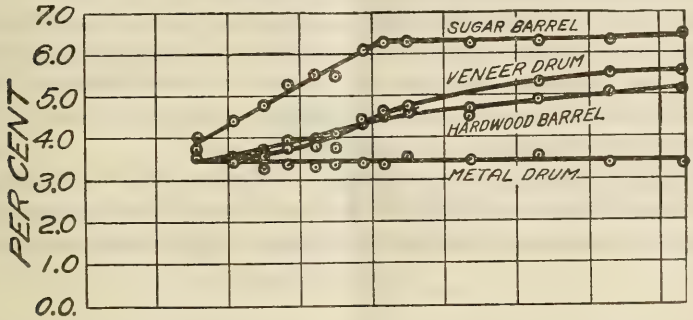

FIG. 51.—Effect of container on absorption of carbon dioxid.

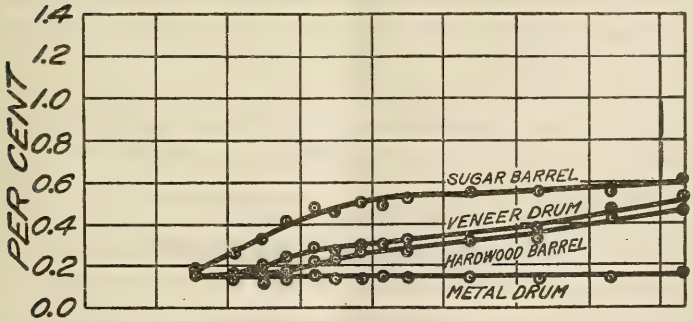

FIG. 52.—Effect of container on water-soluble arsenic oxid.

SUMMARY.

Commercial calcium arsenate in the dry powdered form manufactured for insecticidal purposes absorbs carbon dioxid slowly from the atmosphere during storage and increases in water-soluble arsenic-oxid content, unless it is packed in containers that are practically air-tight. The rates of these changes show a close relationship and depend largely upon the type of container in which the material is packed.

The absorption of carbon dioxid is the first change noted. This is followed a little later by a rise in the water-soluble arsenic oxid

content. Carbon dioxid is taken up until all of the calcium present in the form of the oxid or hydrate is completely carbonated, at which point the increase in water-soluble arsenic oxid also ceases in most cases.

The different types of commercial containers tested may be ranked in the following order: Sheet-metal drum, in which practically no change occurred; heavy hardwood barrel; veneer drums (both unlined and paper lined); sugar barrels (paper lined and unlined).

Of the calcium arsenates examined, none of those stored in sheet-metal drums or in tight hardwood barrels, with possibly one exception, suffered sufficient change in 20 months to be injuriously affected for use from the standpoint of plant toxicity.

In a few cases where calcium arsenate was stored in unlined and in paper-lined veneer drums, and in unlined and in paper-lined sugar barrels, the calcium arsenate at the end of the 20-month period contained soluble arsenic oxid in sufficient amount to make doubtful its safety for application on certain foliage.

The slight changes in the chemical composition of calcium arsenate under certain conditions of packing during long storage can be practically completely avoided by the use of tight sheet-metal drums.

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UNITED STATES DEPARTMENT OF AGRICULTURE

BULLETIN No. 1116

WASHINGTON, D. C. PROFESSIONAL PAPER November 13, 1922

SEEDLING BLIGHT AND STACK-BURN OF RICE AND THE HOT-WATER SEED TREATMENT.

By W. H. Tisdale, *Pathologist in Charge of Smut Investigations, Office of Cereal Investigations, Bureau of Plant Industry.*

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INTRODUCTION.

The rice crop of the southern part of the United States suffers heavy annual losses due to the staining and decay of the grain in the shock and in storage, both before and after milling, and to poor germination of the seed when sown. The former is much more important than the latter. Occasionally fields have to be reseeded, and others have poor stands. The milled product, on the other hand, is considered of inferior quality if only a low percentage of the grain is flecked or decayed. Van der Wolk,[1] in discussing the trouble known to the European rice trade as "yellow grains," says that it is "one of the most fearful calamities in the trade rice of some countries." "Yellow grains" is similar to the stains which develop in our southern rice. It is caused by a different fungus, which accounts for the difference in color. The disease appears in our American rices as flecks or totally decayed grains which are yellowish brown to dark brown in color. The term "stack-burn" often is applied to this form of injury by rice growers and millers. "Stain" and "flecking" are other terms used.

The decay of rice seed in the soil and the staining and decay of the commercial product make investigations for determining causes and

[1] Wolk, P. C. van der. Protoascus colorans, a new genus and a new species of the Protoascineæ group, the source of "yellow grains" in rice. *In* Mycol. Centralbl., v. 3, no. 4, p. 153–157, 1 col. pl. 1913.

means of prevention extremely desirable. Some work was started by the Office of Cereal Investigations in the spring of 1919 at Crowley, La., in cooperation with the Louisiana Agricultural Experiment Station. These investigations were continued for two years, but were given only minor attention because a number of other diseases were considered more important at the time. However, some results were obtained which are thought to be of value, especially to those who may undertake further investigation of these problems.

The investigations reported herein were undertaken with the hope of clearing up the cause of the leaf-spot and seedling blight and, if possible, to find some means of prevention. During the short period of these studies the writer's attention was drawn to what appears to be the more important phase of this problem, namely, the staining and decay of rice in shock and storage. The nature of the marketable product is such that a very small percentage of stain or decay is reflected very decidedly in the grade. As previously mentioned, Van der Wolk states that 0.3 per cent is sufficient to cause rejection in the European markets.

FACTORS FAVORING THE DEVELOPMENT OF THIS DISEASE.

If the harvest season is wet and the rice remains in the fields, especially in shock where it does not dry out, stack-burn is likely to develop. Such rice generally is found of poor quality when milled. This staining of the grain is masked to a certain extent by polishing, but this is only temporary, as the polish gradually disappears and the decay continues to develop. If the rice is stored in a damp place after milling or if not thoroughly dry before storing, it is subject to this type of injury. Repolishing is resorted to at times by millers to mask the discolorations in the rice. This would be more effective if the stains were superficial and were not subject to further development. Rice with slight infections of this type when shipped in damp, warm cars or bottoms for considerable distances, or when allowed to stand for many days under such conditions, may reach its destination with sufficient injury to cause it to be rejected. If not rejected, it would be given an inferior grade on the market. Small flecks, which might escape the observation of the most critical observer, are capable of spreading and destroying the entire kernel when the grain is placed in a warm, damp place. The exact degree of moisture required to cause these stains to develop is not known, but the humid atmosphere of the southern rice sections is known to favor this trouble. High temperatures, which are also common in the South, favor the development of these stains. If the rice is stacked damp or is allowed to go through a sweat after stacking it is likely to become stained if the temperatures remain sufficiently high for a few days.

CAUSES OF INJURY.

The seed-injury phase and symptoms of the trouble were touched upon previously by Godfrey,[2] who reported the occurrence of a leaf-spot on rice in Louisiana in 1916. He said the disease looked very much like the black rust of cereals. Again in 1920, after the writer's investigations were begun, Godfrey[3] reported the occurrence of a seedling disease of rice and states that the cause was found by Dr. H. B. Humphrey to be due to an organism belonging to the *Mycelia sterilia* group of fungi. The fungus was characterized by very small black sclerotia and a white sterile mycelium. He further states that the fungus closely resembles the Sclerotium found associated with the leaf disease reported in 1916. Godfrey found the fungus constantly associated with rice seed grown in Louisiana, particularly the Blue Rose and Honduras varieties. California seed, however, was found to be free from the fungus.

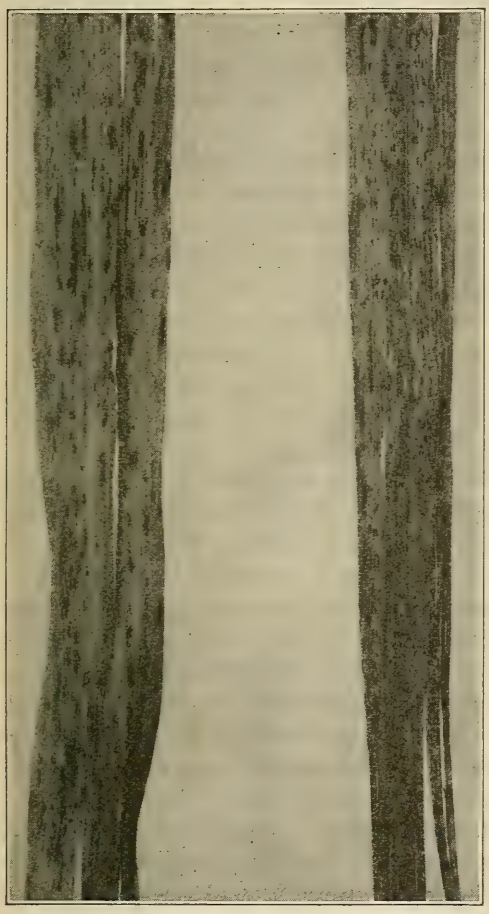


FIG. 1.—Black leaf-spot of rice caused by the sclerotial fungus which produces seed injury and seedling blight.

The cause of these troubles was found to be much more complicated than the notes by Godfrey would seem to indicate. Van der Wolk found the fungus *Protoascus colorans* to be responsible for "yellow grains."[4] The color appeared after the rice had been in heaps for considerable lengths of time. The writer found the small sclerotial fungus of the *Mycelia sterilia* group mentioned by Godfrey[3] to be constantly associated with the leaf-spot (Fig. 1) mentioned by

[2] Godfrey, G. H. Preliminary notes on heretofore unreported leaf disease of rice. (Abstract.) *In* Phytopathology, v. 6, no. 1, p. 97. 1916.

[3] Godfrey, G. H. A seed-borne Sclerotium and its relation to a rice-seedling disease. *In* Phytopathology, v. 10, no. 6, p. 342-343. 1920.

[4] Wolk, P. C. van der. Op. cit.

him and with rice seed grown in the Southern States (Pl. I). However, at least three strains of this fungus were found, basing the difference on size of the sclerotia and the color of pigment produced in certain types of media.

One strain isolated from rice leaves was almost free from pigment in culture; another strain from leaves produced a small quantity of pinkish pigment on most media. One form from rice seed produced an abundance of pinkish pigment, while a second form seemed to be identical with one of the strains from leaves in that it produced a small quantity of pigment. On synthetic agar the mycelium of all forms developed for the most part beneath the surface of the medium, and the size and number of sclerotia produced correlated closely with the pigmentation on other media. The size of sclerotia was directly proportional to the quantity of pigmentation, and the number was inversely proportional. In addition to this sclerotial fungus, a number of fungi were found in the seed which were capable of causing staining and decay and a certain percentage of seedling injury. Among these were some of the common rice parasites, Piricularia and Helminthosporium. Other forms present were species of Epicoccum, Penicillium, Aspergillus, and Eusarium. Other genera occurred rarely and were not given much consideration.

These fungi, no doubt, enter the kernels to a certain extent before they are mature. The spores probably lodge between the glumes at flowering time. Panicles of Honduras rice were collected about the time they were fully mature and were thoroughly dried at once. Seeds from these, 62 in number, were dehulled and treated for three minutes with 70 per cent alcohol. They were then immersed in mercuric-chlorid solution (1 to 1,000) for 10 minutes and placed in tubes of sterile agar and incubated at room temperature. Fungi were found to be present in 27 of these seeds. The percentage of infection was hardly as high as in seed collected from the same field after the rice had stood in the shock through a rainy season.

The infection spreads, no doubt, if the rice remains shocked under warm, moist conditions. At the same time the infections already present have a tendency to spread through the kernels. Under such conditions sclerotia of the sclerotial type of organism are formed in the glumes and on the surface of the kernels. Such infected kernels often are shriveled and very brittle. When conditions are very humid this fungus causes the kernels to become much enlarged and very irregular in shape, with sclerotia resembling those produced by ergot in grain. These distorted kernels are almost black in color (Pls. II and III), and the tissues are filled with a sclerotial development. Where the other fungi mentioned are present the kernels have the brown flecks, and the decayed tissue is a uniform brownish

color. Dark bands of sclerotial tissue may be seen on kernels infected with the sclerotial fungus.

The climatic conditions in the rice-growing sections of the South favor the development of these troubles. The humid atmosphere and high temperatures are conducive to a vigorous growth of the various fungi concerned, and the humidity is unfavorable for the drying and curing of rice, thus leaving it exposed to attacks by these organisms. The drier atmosphere and the rather low night temperatures which generally prevail in the rice-growing sections of California during the crop season probably are not favorable to the development of most of these fungi.

There is one type of flecking known as "blast" in California. In 1919 seed of this type collected at various points in the State was found to contain an Alternaria in the diseased spots. Brown spots or totally brown glumes characterize this trouble. The kernels are also yellowish to brown in color beneath the diseased glumes. Some of the spots have lighter colored centers. The fungus might have been growing as a saprophyte in these dead areas, but the failure to find it associated as constantly with healthy kernels seems to indicate that to some extent it was responsible for the injury. When these kernels were dehulled, surface sterilized, and placed in damp sterile chambers the spots increased in size, and a growth of Alternaria appeared on the surface. Alternaria also was isolated from rice seed grown in Louisiana.

FIG. 2.—Camera-lucida sketch of the germ tube from an Alternaria spore penetrating the epidermis of the leaf of a rice seedling.

In Louisiana a leaf spotting of seedlings was noticed as being quite common before the irrigation water was applied. The spots were small, indefinite in outline, and light brown in color. An Alternaria was found constantly associated with those spots. By examining carefully under the microscope these young leaves, cleared by soaking in equal parts of 95 per cent alcohol and glacial acetic acid, an Alternaria spore could be seen in the center of almost every spot, and often the germ tube could be seen extending from the spore and passing through the epidermis into the leaf tissues (Fig. 2). An Alternaria leaf-spot of black Italian rice and of C. I. No. 1564 was found at Bellflower station, near Los Angeles, Calif., but it was not determined whether or not this was identical with the form producing the "blast" of rice kernels in the Sacramento Valley or with the

Alternaria producing the seedling leaf-spot and seed injury in Louisiana.

Rice infected with the various forms of fungi which produce flecking and decay germinates very poorly as compared with uninfected seed. The germ often is killed by the invading parasite (Pls. II and III, *A*). Wet soils, which tend to check the normal germination and development of seedlings, seem to favor the growth of the fungus, and the seed may be destroyed and a poor stand result. Seed treatment before sowing would not eliminate injury done by these fungi previously, but might prevent further injury and prevent the spread of these organisms. Seed of Honduras rice obtained from California, where seed-infesting fungi are rare, and sown in Louisiana germinated better than seed of the same variety grown in Louisiana (Tables 2 and 4). The difference in the percentages of germination is an indication, perhaps, of the extent of damage commonly caused to seed rice in Louisiana. Of course, if the number of these fungi which may be carried in the soil was considered, the damage might be greater. Treated seed from the same lot germinated almost 2 per cent better than untreated seed. The soil where this seed was sown was in very good condition. The seed was sown late and had almost ideal conditions for germination. This gave the untreated seed an opportunity to germinate before much injury could be done by the fungi carried internally.

SEED TREATMENT.

Upon undertaking a seed treatment it was soon found that surface sterilization was of no value. Seeds were dehulled and treated for 3 minutes in 50 to 70 per cent alcohol and then soaked for 10 minutes in bichlorid of mercury solution (1 to 1,000) with no effect (Pls. IV, *A;* V; and VI, *A*). Godfrey[5] treated dehulled seed by the Jensen modified hot-water method and found that the sclerotial form was killed. Dehulling the seed, of course, would not be at all practicable, so an attempt was made to find out to what extent, if at all, hot water could be used for treating rice in the hull. It was found that practically all the fungi in the seed could be killed without injury to the seed germ if care was exercised in carrying out the treatment.

Rice, which has close-fitting, tough glumes, requires a much longer presoaking in tepid water and a more extended soaking in hot water than the other small grains. The best method found was to presoak the seed overnight in water which was somewhat warm to begin with, and hence more effective than cold water, and then, subsequently, to treat the seed with hot water. Before beginning

[5] Godfrey, G. H. Op. cit. 1920.

the hot-water treatments, tests were made to determine the percentages of rice carrying these fungi internally. The kernels were carefully dehulled, treated 3 to 5 minutes in 50 to 70 per cent alcohol, then soaked for 10 minutes in a 1 to 1,000 solution of mercuric chlorid, and placed in tubes of sterile agar (Pl. IV) or on sterile agar or blotter paper in Petri dishes (Pl. VI) after washing thoroughly in sterile water. The results of these tests are given in Table 1.

TABLE 1.—*Internal infection of rice seeds after surface sterilization in crop varieties grown at Crowley, La., in 1919.*

Variety.	Seeds treated.	Seeds infected.		Variety.	Seeds treated.	Seeds infected.	
		Number.	Per cent.			Number.	Per cent.
Honduras	261	197	75.48	Carolina White	48	46	95.84
Wataribune	60	42	70.00	Shinriki	48	32	66.66

The rice for the tests referred to in Table 1 was taken from the stock seed supply at the Rice Experiment Station, Crowley, La., in the fall of 1919, and the tests were made during the following winter. During the spring of 1920 seeds from a larger number of the best varieties of rice were tested to determine their relative susceptibility to internal seed infection. Of each variety obtained from the seed lots at the Crowley rice station 100 seeds were dehulled and their surfaces sterilized; then they were washed thoroughly in sterile water and placed in sterile moist chambers on damp filter paper. They were allowed to incubate at room temperature for seven days, and the percentages of germination and infection were then taken. No attempts were made to identify the fungi from each kernel. The results of these tests are given in Table 2.

TABLE 2.—*Germination and internal infection of rice seeds grown at Crowley, La., in 1919.*

Variety.	Germination.	Infection.		Variety.	Germination.	Infection.	
	Per cent.	Per cent.	Degree.		Per cent.	Per cent.	Degree.
Delitus (large shocks)	86	50	Slight.	Tokalon	84	38	Slight.
Delitus (small shocks)	64	79	Heavy.	Evangeline	50	95	Heavy.
Blue Rose	92	41	Slight.	Acadia	81	65	Slight.
Vintula	99	35	Do.	Early Prolific	66	49	
Honduras	53	83	Heavy.	Honduras (California)	99	9	Do.
Wataribune	92	25	Slight.	Wataribune (California)	98	7	Do.
Carolina Gold	83	91	Heavy.	Early Prolific (Louisiana)	69	70	Heavy.
Shinriki	63	92	Do.	Honduras (California)	99	25	Slight.
Fortuna	95	38	Slight.	Wataribune (California)	98	8	Do.

In Table 2 the Delitus variety was obtained from both large and small shocks. The harvest season was a very wet one, so the grain in the small shock was injured much more than that in the large or normal shock. The terms "slight" and "heavy," referring to the

degree of infection, represent the rate at which the seedlings were killed or injured by these fungi after the seed germinated. Honduras and Wataribune seed from California, as shown, germinated much better than Louisiana seed of these varieties and were comparatively free from fungi, especially of the types which cause injury.

Honduras rice was selected for the hot-water treatments, as it is a good commercial rice and one of the most susceptible to attack by these internal fungi. Table 3 shows the results of treatments on January 24 and February 2, 1920. The seed was sown in sterile agar plates, 20 seeds per plate.

TABLE 3.—*Effect of hot-water treatment on the germination of Honduras rice seeds and on fungi carried within the seeds.*

Date and number of experiment.	Presoaked in tepid water.	Soaked in hot water.		Germination.	Infection.	Date and number of experiment	Presoaked in tepid water.	Soaked in hot water.		Germination.	Infection.
Jan. 24, 1920: [1]	*Hours.*	*°C.*	*Min.*	*P. ct.*	*P. ct.*	Jan. 24, 1920: [1]	*Hours.*	*°C.*	*Min.*	*P. ct.*	*P. ct.*
No. 1	16½	55	10	83	3	No. 18	(2)	57	15	96	52
No. 2	16½	55	15	78	1	No. 19	(2)	58	15	98	40
No. 3	16½	54	15	87	1	No. 20	(2)	(3)	(3)	96	62
No. 4	16½	56	10	59	13	No. 21	16½	(3)	(3)	92	45
No. 5	16½	56	15	47	3	No. 22	4	(3)	(3)	94	61
No. 6	16½	57	10	43	5	No. 23	2	(3)	(3)	94	67
No. 7	16½	58	10	2	1	Feb. 2, 1920: [4]					
No. 8	4	55	15	93	17	No. 24	16⅔	53	20	90	2
No. 9	4	56	10	91	24	No. 25	16⅔	53	15	91	4
No. 10	4	56	15	85	19	No. 26	16⅔	53	10	86	13
No. 11	4	57	10	66	5	No. 27	16⅔	54	20	76	3
No. 12	4	57	15	75	4	No. 28	16⅔	54	15	93	1
No. 13	4	58	10	72	3	No. 29	16⅔	54	10	81	3
No. 14	4	58	15	74	0	No. 30	16⅔	55	15	71	3
No. 15	2	56	15	89	20	No. 31	16⅔	55	10	91	2
No. 16	2	57	15	78	14	No. 32	16⅔	(3)	(3)	97	52
No. 17	2	58	15	81	15	No. 33	(2)	(3)	(3)	96	47

[1] Soaked at 37° C.; germination in 10 days; infection in 13 days. [2] Not presoaked. [3] Not treated.
[4] Soaking started at 35° C., and the water was then allowed to come to room temperature; germination and infection in 8 days.

Table 3 shows that the long presoaking period is more desirable. In each case the 15-minute treatments at 54° C. gave the best results, in both seed germination and fungus control.

Further tests were made by soaking seed of Honduras rice from Louisiana at 54° C. for 15 minutes, after presoaking 16 hours and 50 minutes in tepid water, and then sowing it along with untreated seed and seed of the same variety which was grown in California. Soil from a field where rice had never been grown was placed in large cans (16 by 16 inches and 15 inches deep), and the 50 and 100 seeds were sown in each can. The soil was in excellent condition, so the seed germinated readily, and none of the seedlings showed signs of blight. Table 4 gives the results of the germination of this seed.

DISEASED AND HEALTHY RICE KERNELS.

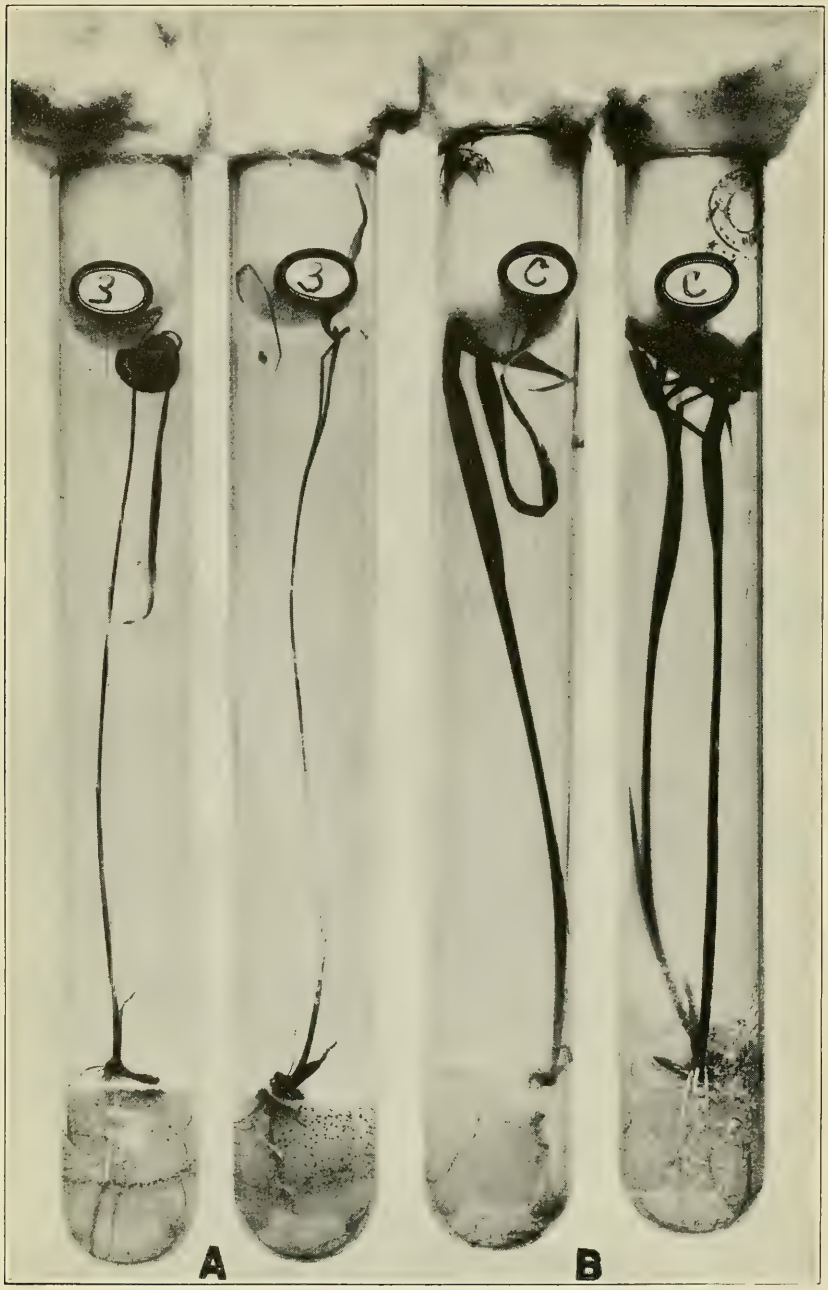
A, Kernels of Honduras rice, enlarged, showing sclerotia on the surface. These kernels were thoroughly invaded by this sclerotial form. *B*, Healthy kernels of the same variety.

DISEASED AND HEALTHY RICE SEEDLINGS AND KERNELS.

At the left is one healthy seedling of Honduras rice. The remainder of the seedlings are infected with fungi, principally the sclerotial form. Note the dark, irregular kernels, which are filled with sclerotial tissue.

INDIVIDUAL RICE KERNELS, SHOWING GERMINATION AFTER SURFACE STERILIZATION AND HOT-WATER TREATMENT.

A, Two kernels of Honduras rice infected with the sclerotial fungus, from a lot which was surface sterilized. *B*, Kernel treated with hot water and sown at the same time as those shown in *A*.

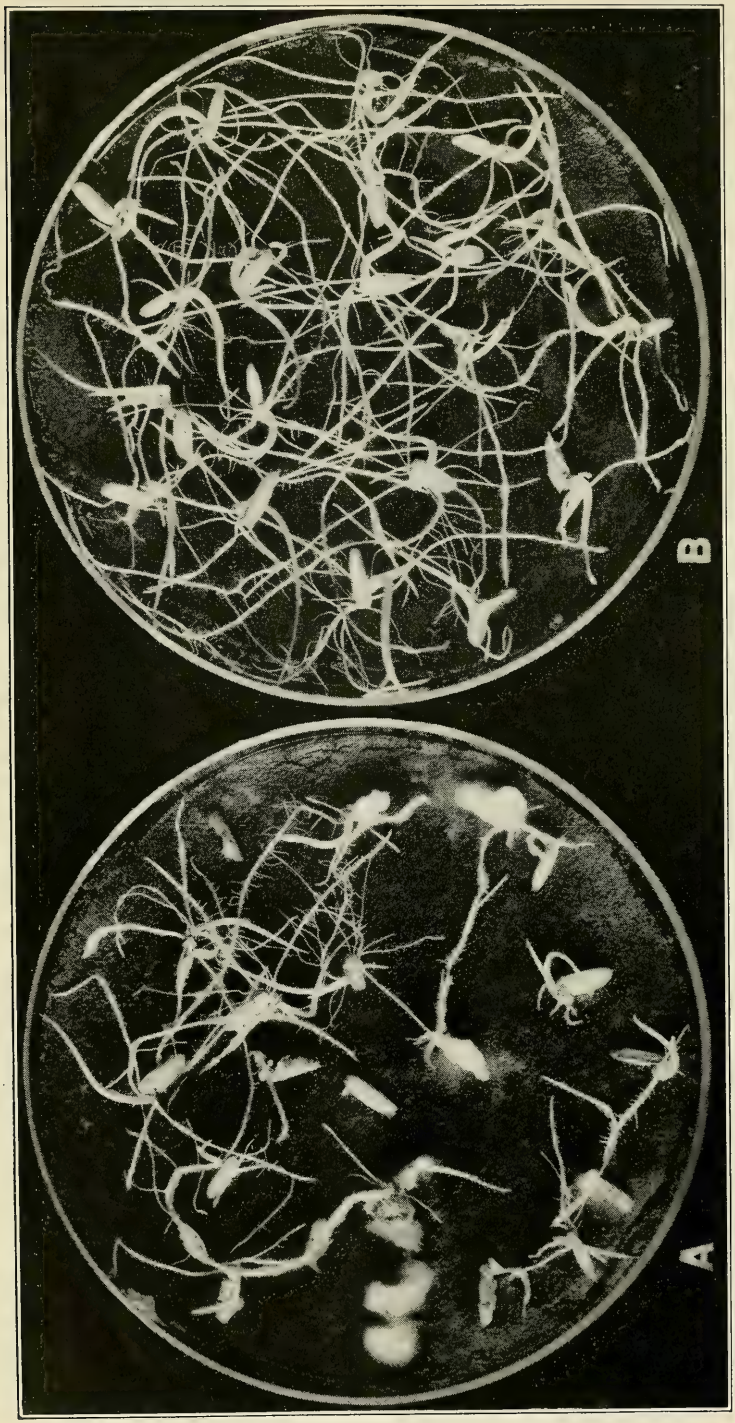


DISEASED AND HEALTHY RICE SEEDLINGS IN CULTURES.

A, Two rice seedlings killed by the sclerotial fungus which infected the seeds. Note the sclerotia in the medium, synthetic agar. *B* Two healthy rice seedlings from clean seed grown in the same medium.

SCLEROTIA ON ROOTS OF RICE SEEDLING.

Test-tube culture, enlarged, showing the sclerotia of the sclerotial fungus developing on the roots of the dead rice seedling. The fungus was carried inside the seed.



GERMINATION OF RICE SEEDS AFTER SURFACE STERILIZATION AND HOT-WATER TREATMENT.

A, Seeds of Honduras rice surface sterilized and sown in sterile Petri dishes on blotter paper. The fungi which developed were carried in the seed. *B*, Uninfected seedlings grown from seed from the same lot as those shown in *A* but soaked 16 hours and treated 15 minutes in water at 54° C.

TABLE 4.—*Germination of Honduras rice seeds from Louisiana treated in water at 54° C. for 15 minutes, after presoaking 16 hours and 50 minutes, as compared with untreated Louisiana and California seeds of the same variety.*

Date sown and number of experiment.	Louisiana seeds.				California seeds.	
	Treated.		Untreated.		Untreated.	
	Number.	Germination.	Number.	Germination.	Number.	Germination.
		Per cent.		*Per cent.*		*Per cent.*
May 3, 1920:						
No. 1			250	52.40	250	55.20
No. 2			250	46.00	250	70.80
No. 3			250	68.40	250	78.40
No. 4			250	64.80	250	64.40
No. 5			250	65.60	250	75.20
No. 6			250	70.80	250	86.40
No. 7			250	72.40	250	84.40
No. 8			250	62.00	250	78.80
May 21, 1921:						
No. 13	400	70.50	200	64.00	400	72.75
No. 14	400	75.00	200	85.50	400	74.00
No. 15	400	65.50	200	65.00	400	63.50
No. 16	500	53.60	500	63.00		
No. 17	500	70.60	500	66.60		
No. 18					1,000	66.10
No. 19	500	63.50			500	73.80
No. 20					1,000	67.00
Total	2,700		3,600		5,700	
Average		65.96		64.80		70.61

Nishikado and Miyake [6] conducted extensive hot-water treatment experiments on the Minaribo variety of rice in Japan. Unfortunately, the results of this work were not available to the writer until after his work on rice was discontinued. These Japanese investigators found that the temperature of the hot water which could be used effectively on rice depended to a large extent on the length of the presoak. They reported no seed injury by treating unsoaked rice for 15 minutes at 55° C. The writer found no injury to Honduras rice when it was treated at 58° C. for 15 minutes without presoak (Table 3).

The Japanese writers mentioned no injury to seed presoaked for different periods up to 16 hours and treated for 5 and 10 minutes in water at 54° C., but a 15-minute soak in hot water caused a slight decrease in germination. Where they presoaked the seed 24 and 48 hours, respectively, a 10-minute soak in hot water at 54° C. caused some injury. Their results also show that seed treated with hot water germinated better than their untreated controls. The writer found that a soaking in water at 54° C. for 15 minutes after presoaking for 16 hours killed the internal fungi and came nearest to giving as good germination as the untreated controls. In practically every case, however, the germination was slightly lower than that of the untreated

[6] Nishikado, Yoshikazu, and Miyake, Giichi. Momidane no shôdoku narabini ine-gomahagarebyô no yobôhô. [Disinfection of seed rice in relation to the prevention of Helminthosporium rice blight.] 1. Momidane no ontô shinsekihô. [Hot-water treatment of seed rice.] *In* Byôchû-gai Zasshi (Jour Plant Protection), v. 5, no. 9, p. 693–712 (1–20). 1918.

controls. The sclerotial fungus seemed to be hardest to kill in Honduras rice.

The Japanese writers were treating for the control of Helminthosporium. They recommended presoaking overnight and soaking with hot water at 54° C. for 5 minutes or at 52° for 10 minutes. They found that the hot-water treatment did not control Piricularia. This was no doubt due to other sources of infection in the field. The hot-water treatment did not prevent the black sclerotial leaf-spot in Louisiana. Treated seed, untreated seed, and clean Honduras seed from California produced plants which were equally diseased. The fungus doubtless lives over in the soil and on old rice straw and infects the rice plants the following season. There are strong indications that this fungus produces conidia which cause the leaf infection. However, this has not been proved definitely. It seems hardly possible that all of the abundant infection which occurs could be caused by sclerotia.

CONCLUSIONS.

The results given in Tables 3 and 4 show that the hot-water treatment will kill the fungi carried within the rice seed and not injure the viability of the seed if the proper methods are used. It also indicates that these fungi have a tendency to lower the vitality of the seed, as is shown by the better germination of seed grown in California, which were relatively free internally from fungi. Hot water does not eliminate this difference but does prevent further development of the fungi in the seed, provided the seed is sown in clean soil where there is no subsequent infection.

Until more information is obtained regarding these fungi and their life histories it would be inadvisable to recommend seed treatment which would kill only the fungi in the seed. Where infested seed is to be sown on virgin soil or soil where rice has not been grown previously, it may be advisable to treat the seed to prevent introducing these fungi into the new lands. Seed from California would be good for this purpose without treating were it not for the numerous weed seeds that might be introduced in this way. The matter of soil infestation by the various fungi concerned has not been investigated sufficiently to show what part it might play in seed decay and seedling blight.

From a commercial standpoint, some form of treatment should be profitable where rice is to be stored or shipped under warm, moist conditions. The hot-water treatment would be too tedious and expensive for treating the commercial product. It is hoped that through future investigations some practicable form of treatment will be discovered. A process of drying under temperatures that would kill the fungi and not injure the texture of the grain might be possible. Van der Wolk [7] recommended the thorough drying of rice and dry

[7] Wolk, P. C. van der. Op. cit.

storage to prevent "yellow grains." Unless the fungi are killed in the process, drying will not serve the desired purpose, as the fungus causing the stains will start developing again if the grain is placed in a warm, damp place.

The most promising solution for these troubles seems to be in the eventual development of resistant strains and varieties. Table 2 shows that some varieties are much more susceptible than others when grown under the same conditions. The varieties which showed the heaviest attacks in these tests are as a rule less hardy and poorer yielders in the field. These seed-infesting fungi evidently have played their part in the varietal selection work where hardy varieties have resulted. With a thorough knowledge of these troubles the problem of breeding hardy strains of rice would be somewhat simplified.

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NATURAL CONTROL OF THE CITRUS MEALYBUG IN FLORIDA.

By A. T. Speare, *Mycoentomologist, Bureau of Entomology.*

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INTRODUCTION.

The citrus mealybug (*Pseudococcus citri* Risso) is widely distributed in Florida and the Gulf States and infests the several varieties of citrus and various other plants cultivated in this region. While it sometimes causes a premature drop of citrus fruit, in most instances more injury is wrought by the sooty mold which develops luxuriantly upon the fruit where the insects are feeding. On the whole, however, the mealybug is considered a pest of secondary importance in Florida, as it usually does not appear in sufficient numbers to arouse the apprehension of the grower. In California, on the contrary, it is looked upon as one of the most serious insect enemies of citrus.[1] The object of the present paper is to show why, in Florida, it is usually unimportant and to point out that a knowledge of its natural enemies is of direct economic value to the citrus grower.

CITRUS CONDITIONS IN FLORIDA.

In Florida, perhaps more than in any other citrus region of the world, are environmental factors conducive to the control of injuri-

[1] Woglum, R. S., and Neuls, J. D. The common mealybug and its control in California. U. S. Dept. Agr. Farmers' Bul. 862, p. 11. 1917.

ous insects by entomogenous fungi. It is favored by a rainy season, more or less well defined, lasting from June to September, which correlates reasonably well with the growing season of the trees. The more important insect pests in a large measure are dependent upon the new growth or "flush" of the citrus trees for their successful development and reproduction. Hence the period of maximum abundance of these insects, which naturally coincides with the period of greatest food supply, at the same time coincides with the rainy season. This is fortunate, for the environmental factors which are normally present in the summer during periods of greatest insect injury are very favorable for the development of the various species of fungi that prey upon and destroy the injurious insects.

These entomogenous fungi are worth millions of dollars to the citrus industry. Owing to their excellent work, oranges and grapefruit are grown at a profit in many parts of the State where no money whatsoever is spent on artificial remedial measures. It should not be inferred that spraying to control citrus pests is not advised. A greater profit can be enjoyed when sprays are employed judiciously, particularly if they are utilized in a way to supplement the work of the fungi, but citrus fruits can be grown at a profit in the absence of any artificial measures, a condition probably not possible, for instance, in the apple industry. The inestimable value of the entomogenous fungi to the citrus grower of Florida is thus evident.

If it were possible to eliminate these organisms from the State and at the same time permit the injurious insects which they attack to remain uncontrolled by artificial measures, the growing of oranges and grapefruit would be an extremely hazardous occupation in which the monetary rewards would be negligible or absent. Other things being equal, it is estimated that in the absence of these fungi the annual citrus crop would be reduced by at least 50 per cent, so great would be the injury wrought by scale insects and the white fly.

These statements are based upon the experience of the Federal agents, the State specialists, and the growers themselves, who, while permitting other factors to function normally, have at times inadvertently or otherwise eliminated in small areas, by sprays of Bordeaux mixture, the entomogenous fungi, which are killed effectively and completely by this fungicide. They have found that trees sprayed with it afford excellent feeding places for the insect pests, and that as the development and reproduction of the latter are unimpeded by the entomogenous fungi, they multiply prolifically, causing heavy defoliation, a very high percentage of fruit drop, and unsightly unmarketable fruit, and even threaten the very life of the trees.

INSECT ENEMIES OF THE MEALYBUG, AND INSECTS ASSOCIATED WITH THE MEALYBUGS AND SOMETIMES CONSIDERED AS BENEFICIAL.

During the past two summers, 1920 and 1921, three insects have been found associated with mealybugs: *Pyroderces rileyi* Wlsm.,[2] *Laetilia coccidivora* Comst.,[2] and a species of Chrysoplatycerus.[3]

The larva of the tineid moth *Pyroderces rileyi*, known as the pink cornworm or scavenger bollworm, is conspicuous in mealybug clusters, occurring abundantly between clustering grapefruit, particularly if dead leaves are pinioned in the cluster. It is perhaps the most common of all insects frequenting mealybug clusters, and many growers are of the opinion that it feeds upon the mealybug. The larvæ are deep pink or "wine red" (Busck[4]) in color, about three-eighths of an inch long, and more or less cylindrical in form. Just back of the head a rectangular, almost black area is to be noted, which, though common to other lepidopterous larvæ, serves at once to distinguish the common Florida form from other larvæ occasionally found in similar situations. The insect is without doubt a scavenger, playing no economic rôle as far as the mealybug is concerned. Busck[4] reported it as a trash feeder. The writer, unaware of this or similar publications, performed some experiments to determine its relationship to the mealybug. A few larvæ brought into the laboratory were confined with live mealybugs in a glass vial for several days, but none of the mealybugs were eaten. On the other hand, an old dead leaf found sandwiched between two grapefruit, covered with the larvæ, was brought into the laboratory and confined in a pill box in a moist chamber. On this the larvæ grew to maturity in the complete absence of mealybugs.

The second insect, the pyralid moth, *Laetilia coccidivora*, is much less common than *Pyroderces rileyi*, but, like it, occurs in the larva stage associated with mealybugs. The writer performed no experiments with this insect, but it is looked upon generally as predacious in habit, feeding upon the mealybugs. In the Winter Haven grove, where the observations of the past season were made, however, it was not abundant, and among the thousands of mealybugs that were collected for experimental purposes only 12 of these larvæ were observed. The full-grown larva is somewhat larger than that of *Pyroderces rileyi* and is grayish green in color. It forms a silken web, beneath which it lives and feeds.

The third insect, new apparently in Florida, is a chalcid, an unknown species of Chrysoplatycerus. The specimens submitted for

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[2] Determined by Carl Heinrich, of the Bureau of Entomology.

[3] The writer is indebted to A. B. Gahan, of the Bureau of Entomology, for the generic identification of this insect and for the information regarding *C. splendens* Howard.

[4] Busck, August. The pink bollworm, *Pectinophora gossypiella*. *In* Jour. Agr. Res., v. 9, no. 10, p. 362, 366, 1917.

determination were immature, and a specific determination was therefore impossible. *C. splendens* Howard, a similar species, is recorded as bred from mealybugs in California, but according to Gahan it was regarded by Timberlake as a secondary parasite. No evidence was obtained that the insect bred from mealybugs in Florida was a secondary parasite, and it is to be inferred from Smith and Armitage[5] that they do not so regard the California form; but as hyperparasitism was not suspected, no particular observations were made to determine this point. Attention was first attracted to certain mealybugs whose bodies were hard and brittle and dark colored, thus contrasting sharply in appearance and characteristics with the bodies of healthy individuals. Upon breaking the body wall of such mealybugs one of the above-mentioned insects was discovered within. Others were subsequently bred out in a normal manner; and although no record of the number was preserved, there were in all not over a dozen, and for that reason these insects can not be looked upon as a considerable factor in the natural control of the mealybug, even if they should prove to be parasitic.

THE FUNGOUS PARASITE ENTOMOPHTHORA FUMOSA, N. SP.

In addition to the insects mentioned, which were, of course, studied more or less incidentally, a fungus was discovered which is unquestionably the chief factor in the natural control of the citrus mealybug in Florida. This parasite was first observed in Florida in 1920 in Orlando, but it had been previously sent to the writer by T. H. Jones, of Baton Rouge, La., where it was collected in 1917 on the citrus mealybug on fig. Mr. Jones subsequently (1920) sent in the same fungus on *Phenacoccus* sp. on Hibiscus from Baton Rouge. While first found in Florida in Orlando, it was later discovered in various regions of the State, extending from Clearwater to Fort Pierce, and there is every reason to believe that it is distributed generally throughout the citrus belt.

The organism in question belongs to the family Entomophthorales, most members of which are entomogenous. Both in appearance and relationship it is entirely unlike the other fungi which have been recorded as occurring upon citrus pests in Florida. A somewhat similar form was described by the writer[6] on the sugar-cane mealybug (*Pseudococcus calceolariae* Mask.) in Hawaii, and what seems to be a very closely related species, *Empusa lecanii*, has been observed on *Coccus viridis* (Green), a coffee pest in Java, although it is impossible from either the text or illustrations to determine definitely

[5] Smith, Harry S., and Armitage, H. M. Biological control of mealybugs in California. Calif. Sta. Dept. Agr., Monthly Bul., v. 9, no. 4, p. 109, 1920.

[6] Speare, A. T. Fungi parasitic upon insects injurious to sugar cane. Hawaiian Sugar Planters' Association, Exp. Sta. Bul. 12, Path. and Physiol. Ser., p. 14, 1912. Honolulu.

whether or not the two are identical. Inasmuch, however, as no resting spores were observed on the Java material, and as the conidia seem unlike those of the Florida form, the writer has chosen to regard the latter as a new species. Zimmerman,[7] in discussing the Java form, described very well the spherical hyphal bodies. It is interesting to note that he observed four nuclei in these cells, and that the writer subsequently found the same number (Pl. I, 10) in the corresponding vegetative stage of the present organism. The conidia were described as pear-shaped, approximately 18 microns long and 9 to 10 microns wide. A dark-colored conidial membrane is also mentioned. Johnston[8] reported a mealybug Entomophthora from Porto Rico which he doubtfully referred to *E. fresenii*. He observed no resting spores, however, and apparently regarded the assignment of this form to *E. fresenii* as tentative. It may be identical with the one herein considered.

As a group the various species of Entomophthora are perhaps the most important natural control agents of insects known among the fungi. Species have been recorded on members of the following insect orders: Diptera, Lepidoptera, Orthoptera, Hemiptera, Coleoptera, Hymenoptera, Neuroptera, Thysanoptera; they have also been recorded on the Arachnida, and the writer has observed a species of the *Grylli* type upon a large myriapod in the vicinity of Washington, D. C. Many of the attacked insects are injurious, as, for example, the brown-tail moth, *Euproctis chrysorrhoea* L., which is destroyed in vast numbers, and in fact this insect is to-day in a virtual state of control in the United States, due largely to the work of *Entomophthora aulicae*.

The citrus mealybug Entomophthora ranks as high as the brown-tail moth fungus as a control agent. That it has passed unobserved—that its work has not been before realized—is due to a lack of knowledge. It has probably been present in Florida for years, exacting an enormous toll of mealybugs year after year, and bringing about, during many seasons, the virtual control of this insect. Such a lack of knowledge doubtless has caused, through misdirected efforts, the waste of much money among the citrus growers in Florida.

While it is sometimes difficult to separate the various species of this genus taxonomically, in the present instance it was not particularly so, as the fungus can not possibly be confused with any known species except the poorly described *E. lecanii*. It possesses resting spores unlike those of any known form, and its conidia are

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[7] Konigsberger, J. C., and Zimmerman, A. De dierlijke vijanden der koffiecultuur op Java. Deel II. Meded. 'Slands Plantentuin, no. 44, p. 16. 1901.

[8] Johnston, J. R. The entomogenous fungi of Porto Rico. Board Comm. Agr. Bul. 10, Rio Piedras, P. R., p. 21. 1915.

likewise quite distinct. In many respects the ubiquitous *E. fresenii* as well as *E. lageniformis*, both aphid parasites, are more nearly allied to it than other known species. The similarity is due to the smoke-colored hyphæ and conidia, the peculiar secondary conidia, and the dark resting spores, characters present in all of the forms which were regarded by Thaxter as sufficiently distinct from the typical Entomophthora, such as *E. aulicae*, to justify a group of subgeneric (*Triplosporium*) value.

DESCRIPTION.

Entomophthora fumosa, n. sp.

Conidia typically more or less fusiform, 16 to 20 microns by 8 to 10 microns, distinctly smoke-colored, tapering rather abruptly toward both the base and apex, occasionally elliptical. Apex sharply rounded, base or papilla weak but clearly visible; conidiophores simple, smoke-colored, slender, arising directly from spherical yellowish hyphal bodies. Secondary conidia elliptical, small, 4 by 8 microns, rather thick-walled, without papillæ, arising on 1 to 5 slender, capillarylike conidiophores from each primary conidium. Resting spores (zygospores?) apparently arising from conjugation of hyphal bodies, spherical, opaquely black, 15 microns in diameter, invariably provided with a hyaline protuberance or appendage. When crushed, black exospore cracks, revealing internal, hyaline, spherical, thick-walled spore. Host attached to substratum by insertion of proboscis.

On *Pseudococcus citri* Risso on *Citrus* spp., Florida; on *Pseudococcus citri* on *Ficus* sp., Louisiana; on *Phenacoccus* sp. on *Hibiscus* sp., Louisiana.

MICROSCOPIC CHARACTERS.

It is a relatively simple matter with a microscope to recognize this disease very early in its development, because the organism which causes it is large and possesses unique characters. Insects which are suspected of having the disease are crushed in water and mounted on a slide. If the organism is present, bodies such as those represented in Plate I, 16, will be observed. Such bodies are always evident if a milky white liquid emerges when the body is crushed, and often they can be detected, though in lesser numbers, before the blood appears white. They have been termed "hyphal bodies" and, while somewhat variable, in so far as shape and appearance are concerned, in the different species of the genus, in the species under consideration they are perfectly spherical, very thin walled, and are filled with a very finely granular protoplasmic content. The wall which surrounds these bodies is exceedingly thin and plastic, as shown by the fact that when pressure is applied unequally upon their surfaces the

wall bulges out in the direction of least resistance, with the result that asymmetrical, egg-shaped, or even dumb-bell-shaped bodies are formed. They represent the vegetative stage of the fungus, the stage in which the parasite grows at the expense of its host. Such bodies live, so far as can be determined, primarily in the blood, absorbing nourishment therefrom, but after having absorbed the blood, or at least after all of the body fluids have disappeared in diseased mealybugs, other tissues break down and evidently furnish additional food. As they grow they reproduce rapidly by a budding-off process. While at first they apparently impede the blood circulation slightly, they later fill up every nook and crevice of the body cavity and must therefore nearly inhibit it. Later the muscles and all other soft tissues are destroyed, leaving only the heavily chitinized structures, until at last the interior of the insect's body is completely and solidly filled. It is at this stage of development, when all liquid matter has been absorbed, that the body cuts like a piece of cheese. This condition marks the end of the vegetative stage.

All subsequent development of the parasite which takes place after the insect is dead is reproductive. Two types of reproductive bodies are formed, conidia and resting spores, the type depending upon factors that are only in part understood. In certain other species they may be formed simultaneously in and on the same individual, though in the present instance resting spores and conidia are not associated in the same specimen. Whichever reproductive body is formed, however, they both arise from the hyphal bodies, which obviously must behave differently in each instance.

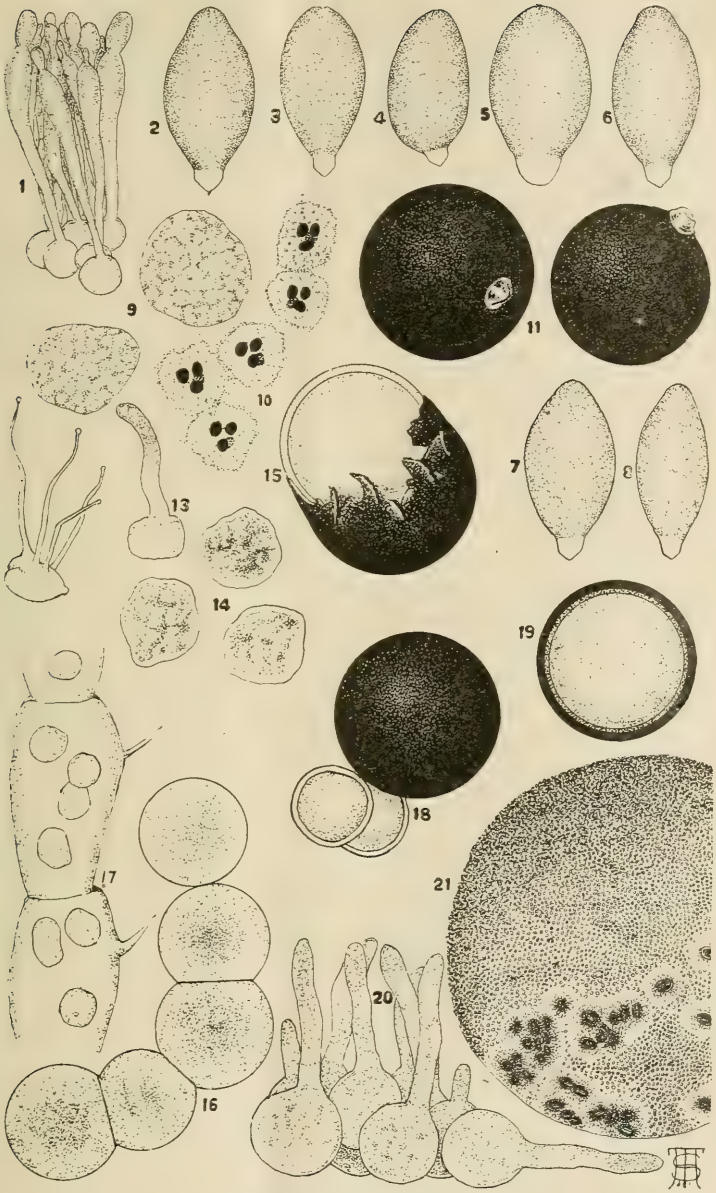
When conidia are to be produced the hyphal bodies send out simple "germ tubes" in the manner shown in Plate I, 20, which bore through the body wall of the host into the open air. Thousands of hyphal bodies produce as many germ tubes, and the latter on the outer surface of the insect's body, together with the conidia which are formed at their tips, cause the slate-gray colored wool-like appearance mentioned below. They stand out from the insect's body in much the same manner as the fascicles of hairs extend out from the body of a hairbrush. They swell up at their tips (Pl. I, 1) and into the swollen portion flows the entire protoplasmic content of the hyphal body and germ tube. By a process which is characteristic of this group of fungi, the swollen portions are cut off from the germ tube by transverse walls, and the resulting fusiform elliptical conidium is literally shot off from the germ tubes. The force by which this is accomplished is considerable, because the conidia are thrown to a distance of 5 or more millimeters. In some species of Entomophthora the conidia are thrown nearly an inch away from the body of the infected host. This phenomenon was observed several times

in connection with *E. fumosa* in the field. When at the proper stage of development, and when touched with a pair of forceps, a minute dustlike cloud, similar to that which arises when puffballs are disturbed, arose from mealybugs that were being collected for laboratory experiments. This cloud was, of course, due to the thousands of conidia which were discharged simultaneously when the body was touched with the forceps. Without such a stimulus the conidia are discharged singly or in very small numbers and are not visible to the naked eye. In *E. fumosa*, however, the force of the discharge, compared with that of many other species, is relatively weak, a fact substantiated by the somewhat slender conidiophores and the comparative weak conidial papillæ.

It is believed that this method of spore discharge is of great value in perpetuating the fungus, in that it aids appreciably in the dissemination of the spores. Citrus mealybugs, while not exactly sedentary insects, are more or less gregarious in their habits and in nature crawl about over one another and huddle together in bunches; hence the value of such a method of spore discharge is not so great as it would be, for example, in a parasite of less gregarious insects, or of those which are more or less peripatetic in their habits.

The conidia or spores of this fungus are probably spread from colony to colony in part by the process just described, in part by insects, particularly ants that frequent mealybug colonies, and in part by air currents, in contrast, in this last respect, to the Aschersonias, which apparently are distributed largely by rain water. While a certain amount of moisture is necessary for the best development of most fungi, a slight increase in humidity such as that which accompanies a heavy dew is sufficient to cause sporulation in the forms like *E. fumosa*, a fact repeatedly observed in Florida during the summer of 1921.

The second type of reproductive development, which results in bodies called resting spores, is totally unlike that noted above, and to one not familiar with the organism involved, the identity of these resting spores might well be obscure. When resting spores are formed there is no external growth whatever upon the insect's body. The spherical, smoke-colored resting spores, opaquely black at maturity, are formed internally directly from the hyphal bodies. They are extremely thick walled and in fact are provided with two walls, each of which is very thick, the outer of these, the exospore, alone containing the black pigment. It is somewhat indurated and cracks rather easily when pressure is applied, separating freely from the inner hyaline endospore (Pl. I, 15). While the germination of these bodies has not been observed, it is believed that they tide the fungus over periods of unfavorable conditions, such as occur, for example, during the winter season in Florida. As already



ENTOMOPHTHORA FUMOSA.

1, Group of conidiophores, showing conidia in various stages of formation, × 164. 2–8, Conidia, × 655. 9, Hyphal bodies, showing appearance when mounted in alcohol, × 655. 10, Hyphal bodies, showing nuclei, × 605. 11, Resting spores, × 655. 12, Germination of conidium, showing capillary-like germ tubes upon which secondary conidia are formed, × 332. 13, "Germinating" hyphal body, × 332. 14, Encysted hyphal bodies sometimes associated with resting spores, × 332. 15, Resting spore crushed, showing inner hyaline endospore, × 655. 16, Hyphal bodies as seen in a water mount. Taken from live mealybugs, × 655. 17, Hyphal bodies in leg of mealybug, × 164. 18, Resting spore with associated hyphal bodies, × 655. 19, Optical cross section of mature resting spore, × 655. 20, Group of germinating hyphal bodies, × 655. 21, Grapefruit, showing diseased mealybugs and discharged conidia of fungus on surface of the fruit. One-half natural size.

noted, this stage has been found much less abundantly in Florida than the conidial stage. This is perhaps due to the fact that the insects in which it occurs are invariably small in size, and usually hidden in bark crevices or other situations where their detection is difficult. The method of formation appears to be zygosporic, but a sexual process has never been actually observed. Specimens have occasionally been observed such as that drawn in Plate I, 18, but the exact nature of the association of the hyphal bodies to the resting spores has not been determined. The mature resting spore, however, is invariably provided with a hyaline papilla or protuberance which indicates that a sexual process somewhat like that described by Thaxter in *E. fresenii*, to which *E. fumosa* is in many other respects similar, has taken place. It is, in fact, difficult to explain the presence of this protuberance in any other way, for no known type of azygosporic formation produces such an appendage.

The nature of the factors which in the one instance cause the hyphal bodies to form conidia and in the other instance to form resting spores is incompletely understood. In certain species of Entomophthora both types are formed simultaneously in and on the same individual, but in *E. fumosa* they are not associated, diseased insects showing either conidia exclusively or resting spores exclusively. In *E. pseudococci* the writer[9] showed that zygospore formation could be readily induced by placing cultures containing "matured" hyphal bodies in darkness, and it seems probable that the same factor plays a part in the present instance, because, while the fungus was collected at various hours of the day, only mature resting spores were observed. None were seen in the process of formation during daylight hours. In certain other similar fungi, such as *Massospora cicadina*, the seasonal factor seems also to play a rather definite rôle. Resting spores of this form are produced late in the season only, after the conidial formation has ceased. In *E. fumosa* resting spores were in fact first observed at the time the mealybugs were becoming noticeably less numerous, though the small size and inconspicuousness of such infected insects may likewise have been factors preventing an earlier discovery.

As in many other species of the genus, the resting spores have never been observed to germinate. Failure to secure germination is apparently due to the fact that suitable artificial environmental conditions have never been supplied. In certain species, such as *E. pseudococci*, however, a germ tube arises from the resting spore which produces a conidium that is discharged in the usual manner; from analogy, therefore, it is believed that a similar process occurs in the species that have not yet been cultivated artificially.

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[9] Speare, A. T. Op. cit.

SYMPTOMS OF THE DISEASE CAUSED BY E. FUMOSA.

The body of a healthy mealybug is more or less pliable, and, when depressed with the point of a penknife, will return to its original position when the pressure is withdrawn, much like a rubber ball. Mealybugs infected with this fungus in early stages of the disease to all outward appearance seem quite healthy, and in fact move about, though in a relatively sluggish manner. If, however, they are pressed with a penknife, the body wall ruptures very easily, permitting a droplet of milky white liquid to exude. When the body of a recently dead mealybug, which is also lifelike in appearance, is treated in this manner the depressed area remains sunken. Mealybugs were considered dead when upon being prodded with a needle no body or leg movement resulted. When the insect has been dead from 12 to 18 hours its body, although remaining lifelike, will appear more or less solid to the touch, and if considerable pressure is applied to the penknife it will cut like a piece of cheese. These are in brief the first symptoms of the disease observed by the writer which can be detected with a hand lens or naked eye. In 24 hours or so after the first of such symptoms have been observed, a change in external appearance takes place. Infected insects at this period and later may present dissimilar characteristics, and by the uninitiated the cause of death would probably be erroneously attributed to different organisms. In the one instance the infected insects appear to be enveloped in a dark slate-gray woolly covering. Such an appearance indicates that the conidia, the thin-walled reproductive bodies, formed externally and abundantly when conditions are favorable for their dissemination, are being produced. In the other instance the infected insects appear jet black in color, sometimes almost glistening, and the body surfaces are smooth, not woolly. The jet-black color is due to the enormous numbers of spherical black resting spores formed internally, the color of which is transmitted through the thin, intact, translucent body wall. Those presenting the first noted characteristics are by far the most abundant, whereas those in which resting spores are formed are rare, detected with difficulty, and occur invariably in young or at least very small individuals. In both instances the infected insects are attached rather lightly to the host by the insertion of their proboscides.

THE FUNGUS IN THE GROVE.

As noted, the fungus has been found in several isolated regions within the citrus belt and is assumed to have a general distribution. Most of the observations herein recorded were made either in Orlando or Winter Park in 1920, or in Orlando and Winter Haven in 1921. In Winter Haven one definite grove was visited at about weekly periods throughout the season.

The earliest seasonal record of the appearance of the fungus is June 13, 1921, when it was found at Winter Haven. While not abundant on this date there was considerable evidence to show that it had been present for some time previously. As the graph (Fig. 1) indicates, it became increasingly prevalent week by week up to August 8, when the last examination was made. At this date so widely scattered were the live mealybugs that a collection of representative specimens was made with difficulty.

Mealybugs of citrus in Florida are more prevalent upon grapefruit than upon orange. (See Fig. 2.) On such trees their favorite feeding location seems to be upon the fruit itself, or upon the fruit pedicels, where they form more or less well-defined colonies. At times they occur along the under side of large branches or limbs of

DATE COLLECTED	JUNE 13	JUNE 22	JUNE 29	JULY 6	JULY 14	JULY 22	AUG. 8
TOTAL NO COLLECTED	406	524	475	350	388	260	295
DEAD FROM DISEASE AT DATE OF COLLECTION	11	28	76	67	89	94	102
TOTAL DEAD FROM DISEASE 7 DAYS AFTER DATE OF COLLECTION	48	106	318	289	312	226	278

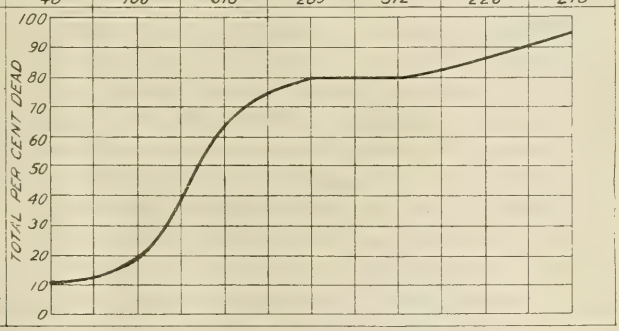

FIG. 1.—Data on collections of citrus mealybugs infected with *Entomophthora fumosa*.

the tree, although it is not known whether they are feeding or not. Mealybugs which frequent such situations are usually those which are ovipositing or about to oviposit. In most instances such insects are enveloped in a mass of wax, the excretion of which precedes or accompanies oviposition. Such a habit favors the spread of the mealybug, because the young crawlers hatching from the eggs will settle, in most instances, upon fresh fruit or twigs some distance away from the spot where the adults found their food. It is not to be inferred that mature females do not also lay eggs upon the fruit, but rather that young feeding individuals are not usually found upon the large branches. The habit of colonization, therefore, together with the white, grayish, or pinkish color of the healthy insects, renders their detection a simple matter.

The grove at Winter Haven was regarded as heavily infested. It was estimated on June 13 that 75 per cent of the trees were supporting five or more large colonies of the mealybug, that 20 per

cent bore one or two colonies, and that 5 per cent were free from the insects.

Infected mealybugs were first detected in this grove upon the fruit. Later in the season they were found nearly as abundantly upon the twigs and branches, where, however, they were detected with difficulty, owing to the neutral gray color of the fungus, which simulates rather closely the bark of the trees. Upon the grapefruit the dead bugs may occur singly, or more often in groups of four or five, huddled together as in life. Surrounding them upon the grapefruit a dark halo was often observed, which might easily be confused with the sooty mold that accompanies the insect. This appearance, however, is caused by masses of conidia which are discharged in enormous numbers and fall upon the grapefruit near or upon one another (Pl. I, 21). Dead insects upon the twigs and branches occur more often singly, most abundant in positions near the colony, but often from 5 to 10 feet away, and in such locations, owing to their small size, inconspicuous color, and position in the crevices of bark, are easily overlooked.

In studying this insect infestation during the period June 13 to August 8, one of the first facts which became apparent was the gradual disappearance, week by week, of young insects or crawlers. The total number of insects collected on June 22 and June 29 was something over 1,500, one-third of which were so young that they were discarded for reasons noted below. In later collections the percentage of young ones decreased markedly until, on August 8, but few young crawlers were observed in the field. It will be observed by reference to Figure 1 that this period of maximum abundance of young insects is likewise the period in which the percentage of diseased specimens jumped from 18 to 64, and it is to be noted that following this sudden increase in mortality the young or crawler insects became less and less numerous.

In order to obtain definite data regarding the prevalence of the fungus at various periods during the season, so that its work might be measured with some accuracy, the following plan was adopted: Collections were made at approximately weekly intervals, an attempt being made to have them representative of the entire grove. The mealybugs were scraped by a penknife from the grapefruit or twigs to which they were attached and placed in ordinary pasteboard pill boxes. Preferably those grapefruit were chosen upon which large numbers of insects occurred, in order to facilitate the collection, but late in the season it became rather difficult conveniently to collect large numbers, as the colonies were decimated and the individuals scattered. In collecting the insects those dead and alive were scraped off indiscriminately, and when taken to the laboratory the crawlers or very small active members were discarded, and those infected with

the fungus were counted either that day or the day following. The remaining insects were then counted, placed in pill boxes with fresh grapefruit rind, and the boxes placed in a moist chamber. Dead specimens were removed daily and counted. They were removed, furthermore, before the fungus fruited, in order to eliminate the chances of new infections arising within the pill boxes from the dead

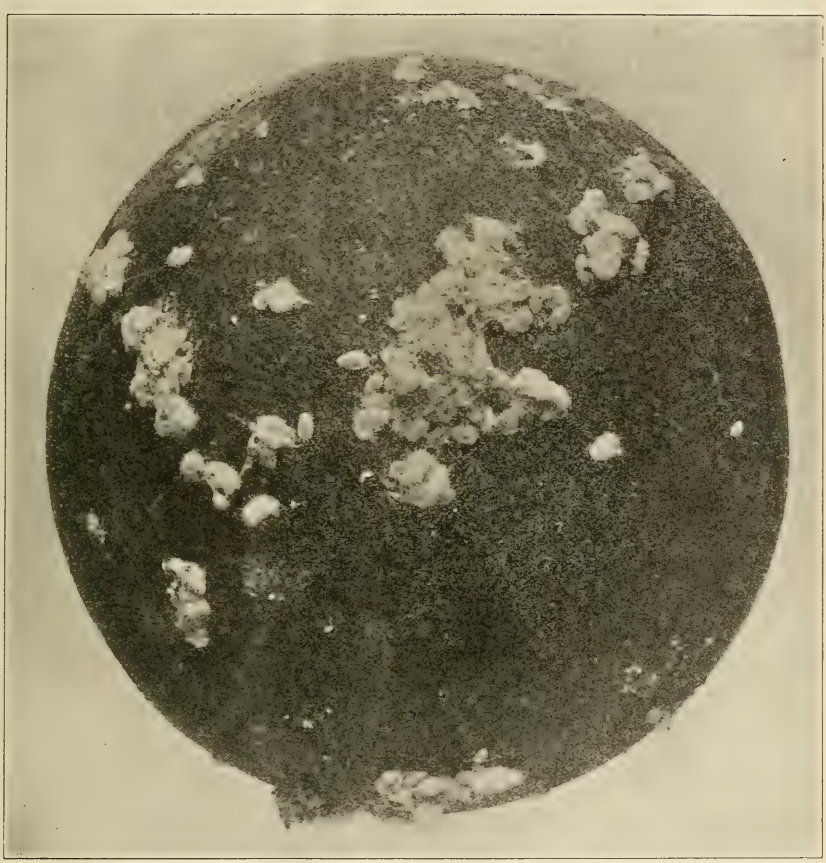

FIG. 2.—"Mealybugs on grapefruit following Bordeaux and oil emulsion for citrus scab. Mealybugs may be equally as abundant when Bordeaux and oil are not applied but such infestations are rather rare." Yothers. (Photograph by W. W. Yothers, 1920.)

specimens. After one week, which was considered ample time for all field infections to become evident, the experiments were closed. When, as occasionally occurred, a mealybug was collected in which Chrysoplatycerus was found, it was removed, but ignored in the count, the number of such specimens being too small to influence the total mortality either one way or the other.

The results of the various collections are diagrammed in Figure 1. It is believed that the progress and increasing rapidity with which the disease spread, as shown in this figure, may be regarded as a

reasonable and fairly accurate check on the activities of the fungus in the field. The table shows that of the first collection on June 13 only 11 per cent died of the disease, whereas in the last collection 94 per cent succumbed; and, furthermore, that the percentage of mortality jumped from 18 on June 22 to 64 on June 29, an increase of 46 per cent in one week's time. The rapidity with which such diseases spread when once established is remarkable, and it is strange that any insects escape alive.

Figure 1 records the events that occurred in one grapefruit grove. It is reasonable to believe, owing to the wide distribution of the fungus, that similar epidemics were present elsewhere, and that as a matter of fact such widespread destruction of the mealybug has been going on for years, unobserved and therefore unheeded by the citrus growers of the State.

RELATION OF FUNGICIDES TO MEALYBUGS.

From the standpoint of the citrus grower, which in fact is the true position for others who make recommendations to assume, insect and fungous enemies are lumped together in one category as injurious factors—factors which among other things tend to inhibit the health and growth of the trees and lower the marketability of the fruit. It is of no concern to the grower whether injury is caused by insects or diseases, except in so far as it is necessary for him to know the differences in order judiciously to apply remedial measures. He sees only the damage caused and translates it into dollars and cents. Unconsciously, perhaps, he mentally segregates these enemies—whether correctly or not is beside the point—into classes, according to the amount of damage or injury they have caused in the past when no artificial measures have been employed to control them. He has formed an opinion, for example, of the relative injury wrought by rust mites, white flies, melanose, scab, the purple scale, etc., and although this opinion may be erroneous, it will influence him in applying control measures. Although most growers would like to control all of their insect and fungous enemies, few attempt to do so. The majority are forced, for what they regard as economic reasons, to control the most injurious. If certain diseases seem to be causing great losses their control will be sought first, or if insect pests are particularly prevalent, these will first be the subject of control measures. In other words, if in the grower's opinion all of the citrus enemies can not be controlled economically, only those will be chosen for control that are causing the most injury. Such a procedure is natural and logical, as the object striven for is economic gain.

The artificial control of citrus diseases in Florida by fungicides and the natural control of injurious citrus insects by entomogenous

fungi are antagonistic, and in view of the effect of fungicides upon the latter, these facts should be kept in mind. It has been repeatedly shown, for example, that Bordeaux mixture, when employed to destroy the organisms causing citrus disease, at the same time destroys the entomogenous fungi; thus the natural balance that otherwise exists, imperfect though it may be at times, but upon which the grower, perhaps unconsciously, has relied, is upset to such a degree that great injury results from attacks by insect pests. Therefore a spray which may be of great importance as a control measure for citrus diseases becomes to a large degree of no commercial importance because the grower must choose either to control the diseases or to permit the natural agencies to control the insects. If he feels that the insects are more injurious than the diseases he will let the entomogenous fungi control the insects, especially since their work is performed at no expense whatever to him. The only alternative is to follow the fungicide with an insecticide, or it may be possible to apply the fungicide and insecticide in one mixture, but these are expensive processes that may prove to be unjustifiable economically.

With regard to the effect of fungicides upon the mealybug fungus, specific data are available in one instance. On August 11 and 12, 1921, a count was made of mealybugs in a grove in Orlando, a part of which had been sprayed with fungicides by the Bureau of Plant Industry, for the control of melanose, and a part of which had not been thus treated. Although some plats were sprayed with Bordeaux plus oil emulsion, some with copper soap, some with barium tetrasulphid, and some with lime-sulphur, for the present purposes all the sprayed trees will be lumped together in one category as "sprayed." While certain of the sprays employed contained an insecticide, the presence of the latter has been entirely disregarded because it has been repeatedly shown that such insecticides are relatively impotent in so far as mealybug control is concerned. In counting the mealybugs such arbitrary categories as "absent," "very scarce," "scarce," "abundant," "very abundant," and "has been very abundant" were employed; and, although crude, these will serve to show the relative degree of infestation. Within the last-named class were included those trees which showed evidences of a previous heavy infestation, but which at the time of the count were free from insects. The other terms are self-explanatory. There were 255 trees in the unsprayed area and 74 in the sprayed. Of the former, 4, or 1.6 per cent, were placed in the class "very abundant" and 6, or 2.4 per cent, in the class "has been very abundant." Of the sprayed trees 6, or 8.1 per cent, showed an infestation classed as very abundant, whereas 1, or 1.4 per cent, in a plat sprayed with lime-sulphur, showed evidences of having recovered from a past heavy infestation.

It is evident, therefore, that so far as mealybugs were concerned the trees in this grove were in better condition in the unsprayed areas than in the sprayed; in fact, there was 5.5 per cent more injury in the sprayed plats.

Observations on the prevalence of the mealybug fungus were made in connection with this count. A dead infected individual here and there in unsprayed areas showed that the fungus had been responsible for the destruction of the colonies included under the caption "has been very abundant." In those colonies classed as "very abundant" the fungus was very noticeable at the time the count was made. On the other hand, in the sprayed area, except for one tree sprayed with lime-sulphur, no fungus was observed, and there were no indications that it had been there previously. A few dead infected mealybugs, however, were found upon the tree sprayed with lime-sulphur.

In brief, this experiment shows that fungicides, with the possible exception of lime-sulphur, prevented the development of the mealybug fungus, which in turn permitted an unrestrained development of the mealybugs. In the grove where this experiment was performed the infestation was very scattered, as shown by the fact that of the 255 unsprayed trees, 185, or 72.5 per cent, were free from the insect.

Considered from the standpoint of a period of years, the mealybug is relatively innocuous as a citrus pest, and it is believed that its commercial control during such periods is brought about by the natural enemies, chiefly the fungous parasite herein described. Seasons obtain, however, such as the summer of 1921, and to a certain extent that of 1920, in which this insect appears in numbers sufficient to arouse the attention of the citrus grower. There seem to occur more or less lengthy periods in which control exists to all intents and purposes, alternating with periods of much shorter duration, lasting but one or two seasons, in which the insect threatens to become a serious pest. Numerical fluctuation of the mealybug is natural and unavoidable, for its control is largely brought about by natural enemies which are dependent for the perpetuation of their own species upon the presence of the hosts which they parasitize, the lack of which, particularly if the parasites are more or less specific, will cause them to disappear. It is very probable in the present instance that a great part of the fungus, which is extremely prevalent when the mealybugs are abundant, dies out for this reason, and in the period of recovery which follows, the host has the advantage and therefore increases in numbers until the parasite once again becomes sufficiently abundant to check it. The grower is concerned only with those periods in which the insect threatens to injure his fruit and trees. At such periods he can either resort to the employ-

ment of artificial methods or he can foster in several ways the development of the natural enemies. Unfortunately, however, no wholly successful artificial control measure is known. Suitable sprays have not been found in Florida. In certain instances a solid stream of water directed at high pressure against the mealybugs in order to knock them forcibly from the trees is advantageous. As the mealybugs' habit of clustering between adjacent grapefruit renders them somewhat inaccessible, however, such a spray must be applied several times for best results, and from the viewpoint of economy is not wholly satisfactory.

It should be remembered that the insect pest herein considered is one that becomes a nuisance periodically only, and that during many seasons it is unnecessary to employ any treatment to control it. The grower has learned that a few scattering colonies of mealybugs do not necessarily indicate that there is going to be a serious infestation, and that often the insects will not become abundant enough to justify spraying. For economic reasons, therefore, he will defer as long as possible the application of any control measure, hoping in the meanwhile that the mealybugs will disappear. Artificial measures are employed only when considerable injury has been wrought and when there are no apparent signs that it is going to cease. The observations of the past two years indicate that the fungous parasite will be invariably present at such times. Inasmuch as the known sprays, while of little value in themselves, actually tend to inhibit the disease in that diseased or dead individuals present at the time of spraying are dislodged, and thereby rendered impotent, while the healthy ones which the sprays do not dislodge or kill remain and reproduce unimpeded by the fungus, it is obvious that in rare instances only will it pay to employ artificial measures. On the other hand, the grower can aid appreciably in restoring the natural balance in his citrus grove by introducing the fungus from available sources as soon as possible in the spring. Unfortunately the organism has not yet been cultivated on artificial media. There is, however, a method by which large quantities of the fungus can be produced. Smith and Armitage[10] have shown that the citrus mealybug can be cheaply and successfully grown upon potato sprouts. With an abundance of insects it is a relatively simple matter to propagate the disease among them. The method employed is substantially the same as that used so successfully in growing large quantities of the brown-tail moth fungus, and consists briefly in obtaining a quantity of diseased insects and distributing them, while yet alive, in the field among the healthy ones. The success of this method depends upon getting the fungus established in the field early in the season. The State or Federal Government should

[10] Smith, Harry S., and Armitage, H. M. Op. cit., p. 121.

undertake the production of quantities of infected mealybugs for the use of the growers.

If, however, a grove has been sprayed for the control of citrus diseases, with Bordeaux mixture or other active fungicide which kills entomogenous as well as other fungi, the owner must be prepared for a heavy infestation of mealybugs, provided, of course, that these insects are present in the grove at the time the Bordeaux is applied. In such instances it would do no good to introduce the fungus and the application of artificial remedial measures might be advisable.

In California the Argentine and other ants are said[11] to be important factors in checking the work of the natural enemies, which in that State, so far as is known, are exclusively insect, or at least not fungus. It is said that they have been observed to carry living mealybugs—

> * * * to destroy and carry off the larvæ and eggs of natural enemies, to interfere with the free movement about the tree of certain beneficial insects, and by their constant attendance upon the mealybugs to prevent normal egg laying and feeding of adult parasites and predatory insects.

Ants have been frequently observed in Florida attending mealybug colonies, but no attempt has been made either to determine the different species involved or their relation to mealybugs, although they were frequently observed carrying these insects. It is difficult, however, to see how they can interfere in any way with the fungous parasite herein considered. unless they possess psychic powers of such a nature as to enable them to pick out for destruction the diseased but not dead specimens, for in carrying about dead sporulating specimens, or even in traveling about among such individuals. they would rather assist in spreading the fungus from insect to insect.

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[11] Woglum, R. S., and Neuls, J. D. Op. cit., p. 11.

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CITRUS SCAB: ITS CAUSE AND CONTROL.

By John R. Winston, *Pathologist, Office of Fruit-Disease Investigations, Bureau of Plant Industry.*

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ECONOMIC IMPORTANCE AND DISTRIBUTION OF CITRUS SCAB.

Citrus scab, or verrucosis (also commonly known as lemon scab, sour-orange scab, sour scab, and grapefruit scab), is a parasitic fungous disease of the twigs, leaves, and fruits of many species of citrus.

Citrus scab occurs in India, South China, Formosa, Japan, Hawaii, Paraguay, Brazil, Canal Zone, Yucatan, Texas, Louisiana, Mississippi, Alabama, Florida, Cuba, Isle of Pines, Porto Rico, and the lesser islands of the West Indies. It is also reported as being in the Canary Islands and the Union of South Africa.

In general importance to the citrus industry, citrus scab is second only to the diseases known as melanose and stem-end rot, caused by *Phomopsis citri* Fawcett. It was largely responsible for the failure of the lemon industry in Florida, which prior to the introduction of citrus scab gave promise of becoming a very profitable undertaking.

Throughout the Gulf and South Atlantic regions, wherever citrus fruits are grown, as well as in Cuba, Porto Rico, and the less important citrus districts in the Caribbean Sea, citrus scab has already become very firmly established and doubtless will increase in importance, especially in those localities where the grapefruit industry

is important. It is not uniformly serious throughout the citrus-growing sections of the Gulf States, but in certain well-defined localities scab is of the greatest importance.

The damage done to leaves on bearing trees is more unsightly than harmful (Pls. I and II; Pl. III, Fig. 2). There is no tangible evidence to show that the functioning power of moderately affected leaves is seriously impaired.

In orchards where a large proportion of scab has recently developed, especially where the infection is serious enough to cause a marked distortion of the fruit (Pl. III, Fig. 1), the dropping of fruit recently set is considerably greater than where scab does not occur in serious proportions. A large percentage of this dropped fruit is distorted by scab. In addition to the rather intangible financial loss brought about by the abnormal early drop of green fruit due to scab infection, a more tangible loss is occasioned by scabby fruit reaching maturity. A badly blemished fruit is a cull; a slightly blemished fruit has to be sold by the producer at a discount of at least 50 cents per box in years of fair prices. An average estimate made by conservative business men familiar with the citrus industry covering the scab losses to citrus growers in Florida is about 1,000,000 boxes infected annually. With the production of citrus fruits in Florida increasing rapidly, the average annual losses from scab are likely to increase. Under the most favorable circumstances the cost of production of grapefruit, kid-glove oranges, tangelos, and lemons of first quality is greatly increased in districts where scab is a serious factor and has to be controlled by sprays.

The damage done to groves before they come into bearing is considerable, but usually not sufficiently great to render control measures imperative. Nevertheless, a reasonable investment in protective measures may be used to financial advantage.

Scab is the only parasitic fungous disease of consequence occurring in the citrus nursery. There it is extremely serious. It produces a very marked stunting effect upon seedling stocks for budding (Pl. IV), frequently reducing the growth by about 40 to 50 per cent. Where citrus scab is held under control vigorous seedlings are sufficiently large to be budded after having been transplanted to nursery rows for a growing season. Where the disease occurs in quantity and is not held in check by treatment, seedlings may require from 2½ to 3 or more years to make sufficient growth to be budded. This disease is of such serious consequence to rough-lemon and sour-orange nursery stock that nurserymen are in search of a desirable stock immune to citrus scab. Grapefruit leaves are most susceptible to infection as they begin to expand. They become entirely resistant to infection by the time they reach a half inch in width. Fruit is susceptible until it is about three-fourths of an inch in diameter.

SPECIES AND VARIETIES ATTACKED.

Among the commercial species and varieties grown under Florida conditions the sour orange[1] (*Citrus aurantium*) (Pl. V, Fig. 2), lemon (*C. limonia*) (Pl. VI, Fig. 2), calamondin (*C. mitis*) (Pl. VII, Fig. 2), and tangelo (a tangerine-grapefruit hybrid) (Pl. VI, Fig. 1) are extremely susceptible to citrus scab. The grapefruit and shaddock (*C. grandis*); the King orange, tangerine, mandarin orange, and Satsuma orange (Pl. I, Fig. 2; Pl. V, Fig. 1), all of the kid-glove group of oranges (*C. nobilis*) and the citrange (a hybrid of *Poncirus trifoliata* and the tangerine) are quite susceptible to infection. The sweet or round oranges (*C. sinensis*) and kumquats (*Fortunella* spp.) are attacked rarely. The Mexican or Key lime (*C. aurantifolia*) and the Royal and Triumph grapefruits (supposed to be hybrids of the orange and grapefruit) appear to be immune. Data on the susceptibility to citrus scab of the less important species and varieties are being accumulated and will be published later.

Since the grapefruit is the commercial type of citrus most affected by scab in Florida, the statements in this bulletin relate particularly to it unless otherwise indicated. Such grapefruit varieties as the Duncan, Walters, Pernambuco, Leonardi, and Foster are susceptible to infection in about equal degree. Hall (*Silver Cluster*) is much more susceptible and the Marsh considerably less so than the above varieties, and these two can frequently be recognized in mixed plantings simply by the relative proportion of scab present. The Royal and Triumph varieties have never been observed by the writer to be infected.

DESCRIPTION OF THE DISEASE.

On bearing grapefruit trees citrus scab usually confines itself to the leaves and fruits, though occasionally it is observed on the calyx (Pl. VI, Fig. 3) and pedicels of blossoms, and on tender twigs. The extremely susceptible species, such as the sour orange and rough lemon, are affected as specified above, and in addition succulent twigs are frequently affected. In the nursery leaves and twigs of the sour orange and the rough lemon may be attacked severely enough to reduce the annual growth to about 60 per cent of normal (Pl. IV). Grapefruit is similarly affected, but very much less so in frequency of occurrence and in degree of injury.

Leaves.—Scab develops first as minute, more or less circular, distinctly raised protuberances, usually on the under surface of the leaf. In a few days the apices of these fresh lesions become cream-colored or pale yellow-orange and plainly evident to the unaided eye. As the leaf expands (Pls. I and II) these lesions become more conspicuous, some forming hollow, conical outgrowths, the apices

[1] The technical classification of citrus species referred to in this bulletin follows W. T. Swingle (*27*). Serial numbers (italic) in parentheses refer to "Literature cited" at the end of this bulletin.

of which are scabby lesions, others coalescing to form more flattened scabs. In severe infections numerous lesions cause a serious distortion of the leaf (Pl. VIII, Fig. 1; Pl. IX, Fig. 2), which sometimes drops as a result of the infection. Later, the lesions become warty (Pl. VI, Fig. 4) and assume a pinkish and still later a dirty olivaceous color, largely as a result of invasion by saprophytic fungi.

Fruit.—The incipient stages of citrus scab on the fruit are essentially the same as on the leaf, except that the outgrowths are solid. The lesions soon become cream-colored or pale yellow-orange and decidedly raised, resulting in more or less distortion of the fruit (Pl. III, Fig. 1). In a few months these spots lose their cream color and usually assume a dusty gray hue. On the grapefruit these protuberances when few in number eventually flatten out, and the fruit regains its normal shape (Pls. X and XI). Lesions on the sour orange and the lemon seldom flatten, but ultimately produce ugly, corky, slightly raised warts (Pl. V, Fig. 2; Pl. VI, Fig. 2). The outgrowths on tangelos are higher and more pointed than on grapefruit and do not flatten as the fruit grows (Pl. XII, Fig. 1).

Twigs.—Infection of twigs takes place for the most part on very succulent growth, such as rapidly growing nursery stock and involves only the most susceptible varieties (Pl. VIII, Fig.1; Pl. IX, Fig. 1). The lesions appear as small cream-colored slightly raised warts, later becoming somewhat pinkish and still later taking on a dusty color, due to secondary invaders.

Several types of injury may be confused with citrus scab. Probably the most frequent confusion is between the so-called thrips injury and old flattened scab lesions. The scars produced by the former are never raised and are much smoother than those caused by scab; they frequently have a characteristic silvery sheen, and the position and pattern are usually distinctive. Another type of injury which causes confusion in the field, even to pathologists, is wind injury to young leaves caused by blowing sand or rubbing effects. This condition is found only on trees exposed to sweeping winds in such positions as are found near a wide expanse of open land or a lake front. Frost injury at a distance may also be mistaken for citrus scab. The minute features are quite distinct.

Citrus canker has been confused with citrus scab because of its warty and corky appearance. An individual citrus-canker lesion grows to be much larger than one of citrus scab. It extends much deeper into the spongy tissue of the fruit rind and entirely through the leaves. The canker spots are surrounded by a yellowish oily zone, which is very distinctive. Citrus canker readily attacks succulent twigs of the common varieties of citrus.

REVIEW OF THE LITERATURE.[2]

It is generally recognized in Japan that citrus scab is a native disease of oranges. Scabby oranges were first called by the native names "abata mikan" (smallpox orange), "kasakaki mikan," and "kasa mikan" (both meaning syphilis-scab orange), according to Nishida (*13*)[3] and Ideta (*9*). The disease is now called "sôkabyô" (Fig. 1, *a*, scab disease), first proposed by Nishida (*14*) in accordance with the American name "citrus scab." This name, however, included not only citrus scab but also citrus canker until the latter was separated by the terms "marugata sôkabyô" (Fig. 1, *b*, round scab disease) and "kankitsu kwaiyobyô" (Fig. 1, *c*, canker disease of citrus) (*29*, p. 7–9).

Probably the earliest mention of citrus scab in Japanese literature is in a manuscript work called "Nankai Hofu" (oranges of the South Sea district) written by Yoshiyuki Murase in 1818. Two kinds of scabby orange were given, with the Chinese names "shitôkan" (Fig. 1, *d*, shih t'ou kan, lion-head orange) and "reishikitsu" (Fig. 1, *e*, li chih chu, lychee orange), the latter bearing the popular name "kasa mikan." These two were illustrated in the "Honzo Dzufu" of Tsunemasa Iwasaki, completed in 1828 (*10*, book 62, fol. 7 and 11). In these early works scabby oranges are treated as particular kinds and not as diseased fruits. It was first proved by Onda (*15*) that the disease was controlled under Japan conditions by spraying with Bordeaux mixture, but according to Hori (*8*, p. 281–282) the disease was given no particular attention by citrus growers until about 1905, when they recognized its disadvantage in connection with the exportation of the Satsuma orange.

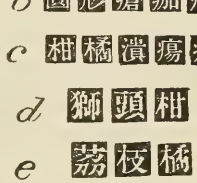

FIG. 1.—Japanese characters for citrus diseases and their hosts: *a*, Sôkabyô; *b*, marugata sôkabyô; *c*, kankitsu kwaiyobyô; *d*, shitôkan; *e*, reishikitsu.

The first report on citrus scab in America was made by Scribner (*19*), who stated that the disease first made its appearance in America in 1885 on sour-orange stock in a citrus nursery near Ocala, Fla. In 1886 it was attacking lemon trees. In a later publication (*20*) on the subject, accompanied by a colored plate of gross and microscopic features, he attributes the disease to a species of Cladosporium, without describing it.

Underwood (*30*, p. 34) confirmed Scribner's findings and reported the disease as occurring very commonly on wild (sour) oranges, frequently on grapefruit and lemon trees, and rarely on sweet-orange trees.

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[2] The abstracts of the Japanese literature on citrus scab were made by Dr. Tyôzaburô Tanaka, of the Office of Crop Physiology and Breeding Investigations, Bureau of Plant Industry.

[3] Serial numbers (italic) in parentheses refer to "Literature cited" at the end of this bulletin.

Swingle and Webber (*28*, p. 20–24) were the first to conduct extensive field studies and spraying experiments for the control of scab. They attribute its cause to a species of Cladosporium and state that so far as is known this fungus is found only on citrus plants affected by this disease. A description of this fungus and spore and hypha (sporophore?) measurements are recorded, as well as the varieties attacked and conditions under which infection takes place. They consider that this disease was undoubtedly introduced into America on the Satsuma orange (budwood) from Japan. Copper sprays were found effective against this disease.

Massee (*12*, p. 310–311) attaches the specific name "*citri* pro tem." to the generic name Cladosporium, not for final acceptance but for convenience in reference. He gives Swingle and Webber's measurements of spores and sporophores and adds a brief description of their form. Briosi and Farneti (*1*) describe the ruggine bianca of lemons in Sicily and state this disease is caused by *Rhynchodiplodia citri*, having several conidial forms, among them *Cladosporium citri*. This organism differs but little from *C. citri* occurring in Japan and America.

In order to correct the confusion between *Cladosporium citri* Massee and *C. citri* Briosi and Farneti, Saccardo (*18*, p. 1366–1367) gives to the latter species the name *C. farnetianum* and records the former as *C. citri* Massee.

In March, 1906, Fawcett (*2*) isolated a hitherto undescribed fungus from sour-orange leaves. He made mention of certain of its cultural characters and used the name *Cladosporium citri* in connection with this new organism. In a later publication (*3*) he calls attention to a series of errors which had crept into the literature in regard to the confusion of *C. elegans* Penz. with *C. citri* pro tem. Massee. Still later Fawcett (*4*) proved by a series of inoculations that the scab is caused by the fungus found by him in scab lesions as early as March, 1906. The characters of this true citrus-scab organism were illustrated and again described. Unfortunately this pathogen was left without a name to distinguish it from the saprophytic organism illustrated by Scribner (*20*) and described by Swingle and Webber (*28*, p. 20–24) and by Massee (*12*, p. 310–311). The result is that two organisms, very distinct in morphological and cultural characters (the one a true parasite, the other a saprophyte) have been referred to in the literature as *Cladosporium citri* Massee. Attempts to find a perfect stage of the true citrus-scab fungus were made by Fawcett without success. Citrus plants subject to attack by this fungus are mentioned and control measures based on spraying experiments suggested.

Stevenson (*24*) emphasizes the influence of weather on citrus-scab outbreaks. His experiments for control show that in Porto Rico (*26*) sulphur sprays were partially effective against citrus scab, while

Bordeaux mixture gave satisfactory control (*25*) and sulphur dusts no control of this disease.

Grossenbacher (*7*) lists susceptible species in Florida and discusses conditions favoring citrus-scab outbreaks. His attempts to produce the disease artificially failed, undoubtedly because he used cultures of the saprophytic *Cladosporium* sp. which develops on old citrus-scab lesions rather than the active pathogen first isolated by Fawcett. Bordeaux mixture proved to be much more effective than lime-sulphur solution against citrus scab. Spraying after the middle of May was found to be too late for effective citrus-scab control. He advises one application of Bordeaux mixture in the height of the bloom, followed in a week or 10 days by an application of lime-sulphur solution and still another application of lime-sulphur solution two or three weeks later.

Fawcett (*5*) reports further confirmative inoculation experiments in producing typical scab lesions by using the true scab organism. He further discusses the confusion of this organism with the common saprophytic Cladosporium.

Lee (*11*) reports finding citrus-scab lesions on leaves of *Citrus nobilis* collected by Maximowicz in 1863 at Nagasaki and deposited in the herbarium of the Hongkong Botanic Gardens. This observation coupled with the fact that scab is distributed throughout the citrus-growing section of South China led him to conclude that this disease may be indigenous to the Orient.

Stevens (*22*) found in avocado-scab lesions an organism in every morphological and cultural character similar to the citrus-scab fungus. With the avocado-scab fungus he produced typical scab lesions on the avocado as well as on the citrus, but the fungus isolated from lesions on citrus failed to infect the avocado. In a later publication (*23*) he predicts that scab will eventually be as severe on the round orange as it is now on the grapefruit.

Fawcett (*6*) reports the results of experiments to determine the effect of constant temperatures on infection of sour-orange leaves and on the vegetative growth and spore development of the citrus-scab fungus. Infection on rapidly growing parts occurred between 16° and 23° C, while detached leaves floated in water were infected at temperature ranging from 16° to 27.5° C. Vegetative growth was most rapid at 21° C. Spores developed at all temperatures from 13.5° to 27.5° but not at 32° C. At 21° C. the spore development was more abundant than at lower or higher temperatures. In the light of these experiments Fawcett thinks the relatively low temperatures of spring tend to aid and the high temperatures of summer in Florida to retard or inhibit infection.

THE CAUSAL ORGANISM.

Citrus scab is caused by a fungus originally isolated by Fawcett (*2*) in 1906 and referred to by him as *Cladosporium citri* Massee. In subsequent publications by various workers the pathogen is referred to by this binomial. This organism (Pl. XIII) has none of the distinctive characteristics of Cladosporium Link. A saprophytic species of Cladosporium develops almost invariably in old citrus-scab lesions and becomes very conspicuous after several months of weathering or after the true scab fungus has largely disappeared. Inoculation tests conducted by the writer at Orlando, Fla. (Table 9), with this saprophytic Cladosporium have given no evidence of any pathogenicity. Since the mycological position of the causal organism has not been established it will be referred to in this bulletin as the citrus-scab fungus, and certain of its cultural and morphological characters will be described to aid in diagnosis.

Its growth on certain nutrient media is characteristic (Pl. VII, Fig. 1), so much so that it can be readily recognized from such reactions. In general the fungus grows slowly, requiring from five to eight days at room temperature for colonies to become plainly visible. When scrapings are made from relatively young lesions very few contaminations develop in the poured plates. Isolations from old lesions which have been overrun by the common saprophytic Cladosporium are more difficult.

One of the best media for isolation and differentiation is glycerine agar. On this medium the fungus produces a distinct purplish color reaction which often becomes plainly visible before growth characters are advanced enough to be distinctive. The prominent growth characters as they appear on the more common media, together with their color reactions, are here given. For convenience in reference to the colors and shades Ridgway's (*17*) standard is used as a basis of comparison, and his plates are indicated by numbers preceded by the symbol R.

PROMINENT GROWTH CHARACTERS.

MOLISCH AGAR SLANTS (FORMULA 1).

Age 7 days: Growth moderate, about 3 millimeters in diameter, restricted, raised about 1 millimeter, convoluted; medium slightly penetrated.

Age 15 days: Growth moderate, about 1 centimeter in diameter, restricted, raised about ½ centimeter, occasionally center of colony more or less villous, convoluted; medium irregularly penetrated but not discolored.

Color of fungus: Ochraceous tawny to cinnamon brown (R 15).

POTATO DEXTROSE AGAR SLANTS (FORMULA 2).

Age 7 days: Growth moderate, about 4 millimeters in diameter, restricted, raised about 3 millimeters; numerous small warts becoming whitish with woolly hyphæ.

Color of fungus: Light ochraceous salmon (R 15) to pallid vinaceous drab (R 45).
Age 15 days: Growth moderate, about 1 centimeter in diameter, restricted, raised about 0.5 centimeter; numerous small warts covered with pale woolly hyphæ irregularly penetrated and rendered dusky auricula purple near colonies.
Color of fungus: Vinaceous buff (R 40) to pallid purple drab (R 45).

BEEF AGAR SLANTS (FORMULA 3).

Age 7 days: Growth moderate, about 5 millimeters in diameter, restricted, round, warty.
Color of fungus: Wood brown.
Age 15 days: Growth moderate, about 7 millimeters in diameter, restricted, raised; center warty, edges distinctly convoluted; media color unchanged.
Color of fungus: Clay (R 29) to ochraceous tawny (R 15).

GLYCERIN AGAR (FORMULA 4).

Age 7 days: Growth scant, about 1.5 millimeters in diameter, restricted, center raised, villous, border flattened; medium slightly penetrated.
Color range of media and fungus: Perilla purple (R 37) to pale purple-drab or pallid vinaceous drab (R 45).
Age 15 days: Growth poor, about 5 millimeters in diameter, restricted, raised; covered with dense, short woolly hyphæ, border flattened, villous; medium moderately penetrated.
Color of fungus: Pallid vinaceous drab (R 45). Media close to colonies, Corinthian purple (R 38) to dull Indian purple (R 44).

TOMATO AGAR (FORMULA 5).

Age 7 days: Growth moderate, about 3 millimeters in diameter, restricted, raised, convolute; medium irregularly penetrated.
Color of fungus: Ochraceous tawny (R 15) to wood brown (R 40) or pale vinaceous drab (R 45).
Age 15 days: Growth good, about 1 centimeter in diameter, restricted, raised, warty, covered with dense, short woolly hyphæ; medium irregularly penetrated, medium color unchanged.
Color of fungus: Pallid vinaceous drab (R 45) to light cinnamon drab (R 46).

MEDIA FORMULAS.

The media used in these cultural studies were made according to the following formulas, titrated to Fuller's scale, using phenolphthalein as indicator, and autoclaved at 15 pounds pressure.

Formula 1. Molisch medium (*21*, p. 198) modified (acidity 7): Water, 1,000 cubic centimeters; agar agar, 20 grams; cane sugar, 20 grams; peptone, 10 grams; dipotassium phosphate, 25 grams; magnesium sulphate, 25 grams.

Formula 2. Potato-dextrose agar (acidity 12): Water, 1,000 cubic centimeters; white potatoes, 500 grams; dextrose, 20 grams; agar agar, 20 grams.

Formula 3. Beef agar (acidity 10): Water, 1,000 cubic centimeters; agar agar, 20 grams; peptone, 10 grams; beef extract, 3 grams; sodium chlorid, 5 grams.

Formula 4. Glycerin agar (neutral): Water, 1,000 cubic centimeters; glycerin, 20 cubic centimeters; agar agar, 20 grams.

Formula 5. Tomato agar (acidity 15): Fresh ripe tomato juice, 200 cubic centimeters; water, 1,000 cubic centimeters; agar agar, 24 grams.

In addition to these media, the fungus has been grown on cornmeal agar, prune agar, nitrogen-free agar; on clover stems, bean pods, and orange stems; and on celery, carrot, tomato. bean, peach, apple, and prune broths.

DEVELOPMENT OF SPORES.

True conidia (Pl. XIII, Fig. 9) are borne very sparingly in culture, so much so that they are not considered in this bulletin. Secondary colonies developing in test tubes are rather unusual. As cultures age the convoluted mycelium rapidly becomes thick-walled and develops tangled chains of more or less regularly constricted hyphæ. These convoluted chains are easily broken apart into many single-celled thick-walled bodies, apparently chlamydospores, which possess the power of germination (Pl. XIII, Figs. 1 to 7) and which are most likely responsible for the greater part of the infections induced by artificial inoculations from cultures.

TEMPERATURE RELATIONS.

In order to determine the effect of temperature upon the radial growth of the citrus-scab fungus on artificial media a relatively large number of cultures were held for 42 days at various temperatures. In each tube a bit of fungus tissue not more than 0.5 of a millimeter in diameter was planted as near as possible in the center of the slant surface. The media used were potato-dextrose agar, glycerin agar, beef agar, and Molisch agar. The strains used were isolated from various susceptible citrus varieties, but no appreciable variation could be noted between the several cultures. The average final diameter of colonies on the several media is the basis of comparison of growth as here recorded in Table 1.

TABLE 1.—*Growth of citrus-scab fungus attained in 42 days at various temperatures.*

Colonies.	Temperatures (° C.).							
	0	5	15	20	18 to 25 (room range).	28	36	45
Diameter.....millimeters..	1	2	8	10	12	7	2	0

It will be seen that around 20° C. (68° F.) is probably the optimum temperature for the development of the fungus in culture. This in a measure may account for the relatively large proportion of citrus-scab infection which occurs during the cool weather of spring. Nevertheless an abundance of infection occurs in the hot summer months as well.

OVERWINTERING.

In order to determine whether or not the citrus-scab fungus lives over winter on fruit or leaves, or both, a number of isolation tests were made at various times during the past four years. Invariably

an abundance of scrapings from citrus-scab lesions not previously disinfected were placed in sterile Petri dishes, covered with glycerin agar or potato-dextrose agar, and held at room temperature for 10 or 15 days before making final records. Table 2 gives the result of these isolation tests made for the most part in the laboratory at Orlando, Fla.

TABLE 2.—*Results of isolation tests of citrus-scab fungus from citrus fruit and leaves.*

TESTS OF LEAVES.

Date of isolation.	Host.	Growth developed.	Remarks.
Dec. 11, 1916	Grapefruit	Spring, 1916	Very many colonies.
Do	Round orange	do	Many colonies.
Feb. 14, 1917	Grapefruit	October, 1916	Very many colonies.
Feb. 15, 1917	King orange	Spring, 1916	Do.
July 27, 1917	Satsuma orange	Spring, 1917	Do.
Feb. 10, 1918	Sour orange	do	Many colonies.
Do	Rough lemon	do	Do.
Do	Grapefruit	do	Do.
Feb. 20, 1919	Sour orange	Spring, 1918	Very many colonies.
Do	Rough lemon	do	Do.
Do	Grapefruit	do	Do.
Feb. 10, 1920	Tangelo	Summer, 1919	Do.
Do	Calamondin	do	Do.
Do	Sweet bittersweet	do	Do.
Oct. 24, 1920	do	Spring, 1920	Many colonies.
Nov. 5, 1920	Sour orange	do	Do.
Nov. 19, 1920	do	do	Do.
Feb. 6, 1921	Grapefruit	do	Do.
Mar. 8, 1921	do	do	Do.
May 9, 1921	do	do	Do.

TESTS OF FRUIT.

Date of isolation.	Host (grapefruit).	Fruit set.	Remarks.
Feb. 15, 1917	¾-inch diameter	December, 1916	Very many colonies.
May 27, 1920	Green, 1½ inches diameter.	March, 1920	Do.
June 10, 1920	Green, 2 inches diameter.	do	No colonies.
June 23, 1920	2½ inches diameter	do	Do.
Do	do	do	Do.
July 20, 1920	3¼ inches diameter	do	Do.
Oct. 24, 1920	Half colored	do	Do.
Nov. 5, 1920	do	do	Do.
Nov. 19, 1920	Three-fourths colored	do	Do.
Feb. 6, 1921	Mature	Spring, 1920	Do.
Mar. 8, 1921	do	do	Do.
Mar. 9, 1921	do	do	Do.
July 23, 1918	Ripe	December, 1917	Do.
Feb. 10, 1920	do	December, 1919	Do.

These tests show that when once the scab fungus enters a leaf, it can persist there throughout the winter. This finding is corroborated by a large number of field observations in which new flushes developing in close proximity to hold-over lesions were seriously affected by scab while more distant flushes were scab free.

The isolation experiments further show that the causal organism does not persist for any great length of time in fruit. It seems reasonable to conclude from cultural data and field observations that the disease is seldom if ever carried over winter on fruit set in the spring or summer.

PATHOLOGICAL ANATOMY.

Microscopic examinations of the lesions, especially those on leaves, show that the fungus forms a compact stroma of convoluted thick-walled hyaline mycelium. From this base numerous hyaline sporophorelike bodies arise, but as yet the writer has not found spores attached to these specialized hyphæ. Beneath the stroma a rather loose, coarse, thick-walled hyaline mycelium penetrates the host intercellularly for a distance of several cells. The host tissue in close proximity to the fungus rapidly becomes brown and distorted. Distinct hyperplasia is often in evidence beneath the area attacked by the fungus, which fact probably accounts for the plainly evident excrescence associated with scab lesions (Pl. XIV).

Specialized host tissue can frequently be found separating the invaded from the uninvaded parts. This condition occurs in older leaves. It has not been observed in leaves incompletely expanded.

As the leaf ages, secondary fungi, principally Cladosporium and Colletotrichum species, invade the lesion and soon partially mask the pathogen. This invasion may take place within a few days after primary infection occurs, but usually does not become very evident until the lesions are several weeks or months old. The older the lesion becomes the less conspicuous the causal organism appears. Frequently the stroma which was conspicuous in young scars disappears by fall or winter, leaving only fragmentary bits of the pathogen on the host. The stroma which persists in citrus-scab lesions through the winter becomes especially thick walled. When that stroma is placed under the microscope and a slight pressure exerted on the cover slip the fungal mass frequently separates into many thick-walled single-celled bodies, indicating that under certain natural conditions this stroma may possibly be separated into many sporelike bodies.

DISSEMINATION OF THE CAUSAL FUNGUS.

The agencies employed in the dissemination of the citrus-scab fungus are doubtless the same as those that aid in the spread of most diseases. Frequent relatively high winds accompanied by stormy periods occur in the spring about the time the leaves or fruit are susceptible to infection. A large number of observations have indicated that storms play an important part in spreading the fungus from tree to tree. This dissemination of the fungus from infected trees, however, is hardly comparable with the distinct path of invasion made by such diseases as cedar rust or scab of apple. The spread of citrus scab is very erratic. It may persist for a number of years on a small group of trees or even a single tree without increasing its distribution, or it may spread very gradually over an orchard, or it may suddenly become pandemic over a large, hitherto apparently scab-free, isolated property. On the whole, the fungus is gradually

gaining entrance into sections hitherto free from this disease and in many places increasing where already established.

The exact part of the fungus concerned in dissemination is questionable. Most writers attribute it to spores produced in scab lesions. In order to determine this point, a great many microscopic examinations were made of old and young scab lesions at various times during the past four years, especial attention being given to it during periods of scab outbreaks. Hundreds of sections were examined, but in no instance were conidia of the causative organism found. That the fungus was present and alive in both the old and young lesions at the time of microscopic examinations was proved repeatedly by cultural methods.

There appear to be no available data to show that the fungus in such lesions produces conidia in sufficient numbers to account for the widespread and rapid primary infections occurring under favorable conditions. At various times attempts were made to find a perfect stage of the causal organism. These efforts were futile.

Attention is called elsewhere to the gross appearance of the fungus in citrus-scab lesions on leaves and to the ease with which the fungal mass is divided into many thick-walled single-celled bodies called chlamydospores which are doubtless responsible for a great part of the primary infections occurring in early spring.

In addition to old lesions abundantly supplied with a hold-over stroma, many scars occur in which the stromatic mass has weathered away. There is a marked flaking off of host and fungal (mycelial) fragments from such lesions during the early spring, so much so that pure cultures can be isolated easily from such scales by holding an affected leaf over an open Petri dish and brushing the lesions. This indicates that spring infection in part at least may be attributed to fragments of host and parasite flaking from these lesions.

Regardless of whether the disease starts in the spring from chlamydospores or fragments of host and fungus, there is no tenable evidence to show that citrus scab is spread for the most part by conidia produced in these old lesions.

CONDITIONS INFLUENCING INFECTION.

Local and seasonal conditions play an important part in the dissemination and propagation of this disease. In years of rainy springs citrus scab is almost certain to be severe on grapefruit, provided the rainy periods occur while the leaves or fruit are in a stage of development susceptible to infection. It is a matter of common remark among growers that citrus scab is very likely to be serious if rainy spells occur during or soon after the blossoming period.

If the vegetative flush precedes the opening of the bloom during weather that is then dry and warm very little infection is likely to

occur on leaves, but should rainy weather occur during or soon after the bloom, the fruit is likely to be infected though the leaves escaped. If the weather reverses its order the leaves are likely to be infected and the fruit remain free from scab.

In localities where heavy dews or fogs occur normally during the critical period, or in orchards on low hammocks or flatwood soils, which are usually damp locations, scab is commonly quite severe even during springs of minimum rainfall; and the June bloom fruits, as well as the leaves expanding during the rainy season, are almost always very severely attacked. In the high, dry rolling hill country citrus scab is a negligible factor during ordinary years and only becomes serious during years which are unusually favorable for its development. Ordinarily in such localities the June bloom fruit is only moderately affected, if at all.

In a very excellent article, Fawcett (*6*), among other data, gives the results of inoculations with the citrus-scab fungus held at definite maintained temperatures together with a statement of the failure of inoculations made in Florida during August under natural conditions and the success of those made in January. He concludes that other factors being favorable natural infection is largely dependent upon temperature ranging from 16° to 23° C. (61° to 73° F.); that infection is likely to occur when the mean temperatures are well within that range and unlikely to take place when the mean temperatures are outside of that range. He says:

> In the light of these temperature experiments, the greater severity of scab at low temperatures in Florida seems to be due largely to the fact that these temperatures fall mainly within the range for infection, while the later spring and summer temperatures are usually too high for infection to take place, even though other conditions are favorable. . . . This last statement may be translated into terms of mean temperatures, to the effect that severe infection will usually occur when the mean temperatures are well within the infection range and that infection will be unlikely to take place when the mean temperatures are outside this range.

Such a conclusion is doubtless in a measure correct, but it is by no means entirely in keeping with the normal behavior of the disease on the several citrus hosts. On the same tree June bloom grapefruit is frequently more severely attacked than that resulting from the spring bloom. Citrus scab attacks nursery stock equally if not more severely in the hot summer months than is the case during the cooler seasons. This is to be expected, since even in warm months the night temperatures usually drop within the optimum range indicated by Fawcett.

In recent years in Florida citrus scab was most prevalent during the seasons of 1914 and 1915 and least so during 1921. A study has been made of the precipitation and mean temperatures at Orlando during the months of January, February, March, and April of the years 1914, 1915, and 1921. These are presented in Table 3.

TABLE 3.—*Mean temperature and precipitation at Orlando, Fla., during the months of January, February, March, and April in the years 1914, 1915, and 1921.*

[Temperature data are stated in degrees F., precipitation data in inches.]

Year.	January.				February.			
	Temperature.		Precipitation.		Temperature.		Precipitation.	
	Mean.	Departure from normal.	Total.	Departure from normal.	Mean.	Departure from normal.	Total.	Departure from normal.
1914	69.4	+0.2	5.23	+2.83	62.2	+1.0	3.31	+0.62
1915	58.7	−.5	4.36	+1.96	60.3	−.9	4.34	+1.65
1921	63.7	+3.5	.52	−2.08	64.1	+2.6	1.76	−.89

Year.	March.				April.				Total departure from normal.	
	Temperature.		Precipitation.		Temperature.		Precipitation.			
	Mean.	Departure from normal.	Total.	Departure from normal.	Mean.	Departure from normal.	Total.	Departure from normal.	Temperature.	Precipitation.
1914	62	−5.6	2.10	−0.20	72.9	+2.1	2.25	+.29	−2.3	+3.54
1915	59.2	−8.4	1.41	−.89	68.4	−2.4	.10	−1.10	−12.2	+1.62
1921	73.2	+5.8	.87	−1.44	72.6	+1.5	1.51	−.82	+13.4	−5.23

It will be noted that the mean temperatures for all three seasons are reasonably well within the infection range mentioned by Fawcett, while the rainfall was above normal during 1914 and 1915, years of citrus-scab abundance, and considerably below normal for the same period in 1921, when citrus scab was very slight. Figure 2 shows the daily range of temperature and the precipitation during these four months of 1915, while Figure 3 is a thermographic record [4] for a representative week during the scab season. Figure 4 gives the temperature range during the comparatively scab-free spring of 1921. With the progress of the rainy season of the summer of 1921 numerous complaints were registered in regard to a severe citrus-scab outbreak on the current crop of June bloom fruit, especially on trees which showed little or no spring infection but abundantly supplied with affected leaves from the 1920 growth. Many nurseries which were only slightly affected with scab during the spring of 1921 were very severely attacked during the summer of that year. It thus appears that infection is possible over a wide range of temperatures, and that moisture conditions during periods when young flushes are putting out determine in the main the seasonal prevalence of citrus scab.

Conclusions regarding the general behavior of the disease on its several hosts when based on the behavior of the disease on bearing

[4] The graphs shown in Figures 3 and 6, while not dependable for maximum and minimum range, give a rather accurate account of the length of time that the high and low temperatures were maintained.

grapefruit are likely to be misleading. Rough-lemon and sour-orange nursery trees are exceedingly susceptible to scab infection and are equally affected if not more severely attacked during the hot rainy summer season than is the case in the spring. That this condition exists is corroborated by letters on file in the Office of Fruit-Disease Investigations from five of the larger commercial nurseries in Florida.

The United States Department of Agriculture maintains a nursery of rough-lemon, sour-orange, and grapefruit seedlings at Orlando, Fla., for experimental purposes. This nursery was set out in March, 1918. The flushes which developed during April and May of that year

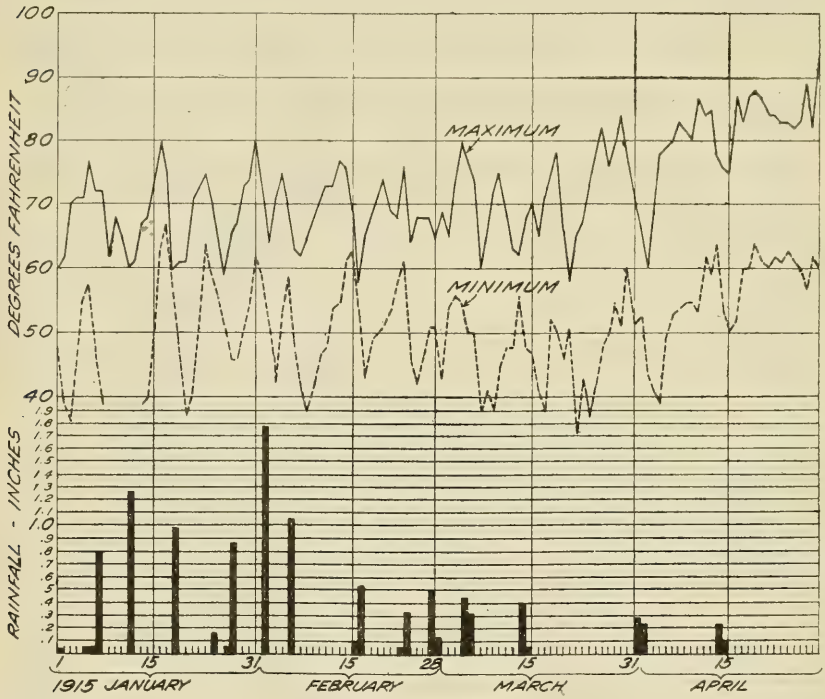

FIG. 2.—Precipitation and maximum and minimum temperatures at Orlando, Fla., during January, February, March, and April, 1915—a year of severe scab infection.

were affected by citrus scab, but not nearly so severely as was the case during the rainy summer weather. The flush which developed late in the fall was comparatively free from citrus scab, in spite of foci of infection on the older leaves. Similar conditions were noted in this nursery during the years of 1919 and 1920, viz, scab attacks the nursery stock more severely during the rainy season in summer than is the case during the spring or fall. As stated in another place, the spring of 1921 was quite dry. Little or no citrus scab developed in this nursery during that period. The same applies to a new seed bed of similar seedlings. As soon as the rains set in citrus scab im-

mediately became severe in this seed bed and increased rapidly in the nursery.

During 1916, 1917, 1918, 1919, and 1920, the outbreaks of citrus scab in the bearing grapefruit orchards of Florida were in approxi-

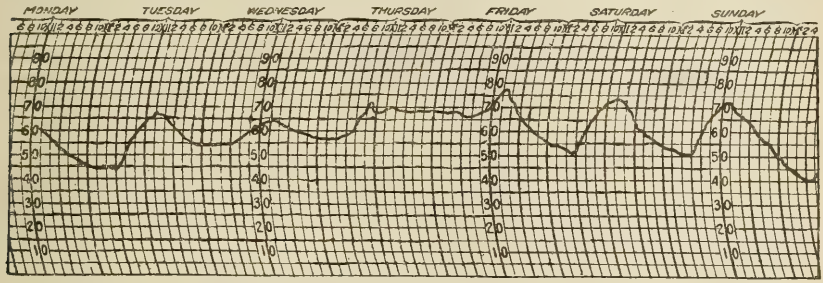

FIG. 3.—Thermographic record of a typical week during the scab infection period, Orlando, Fla.

mately average proportions, varying considerably from one locality to another. These outbreaks were very sporadic and, with but few exceptions, could not be anticipated. Often the disease did not

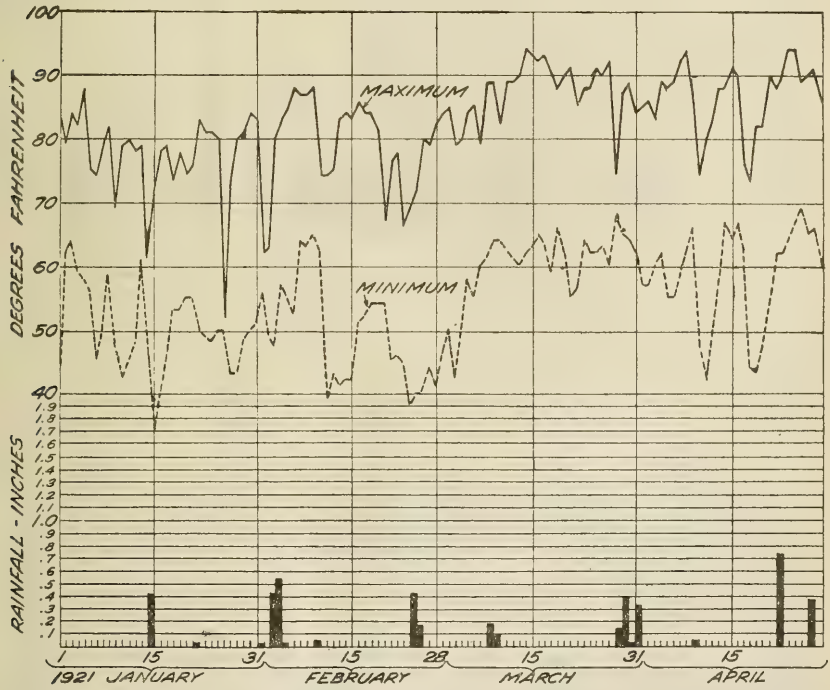

FIG. 4 —Precipitation and maximum and minimum temperatures at Orlando, Fla., during January, February, March, and April, 1921—a year of very little scab infection.

develop in orchards with an abundance of scab on the old leaves, but became rather prevalent in properties hitherto apparently free from scab. On the other hand, sour-orange and rough-lemon nursery stock became severely affected during the spring of those years.

The only apparent explanation for this condition is that the rainy periods were not of sufficient proportion or duration at the proper time to be responsible for general outbreaks in orchards. However, in certain localities the proper timing of the necessary factors for com-

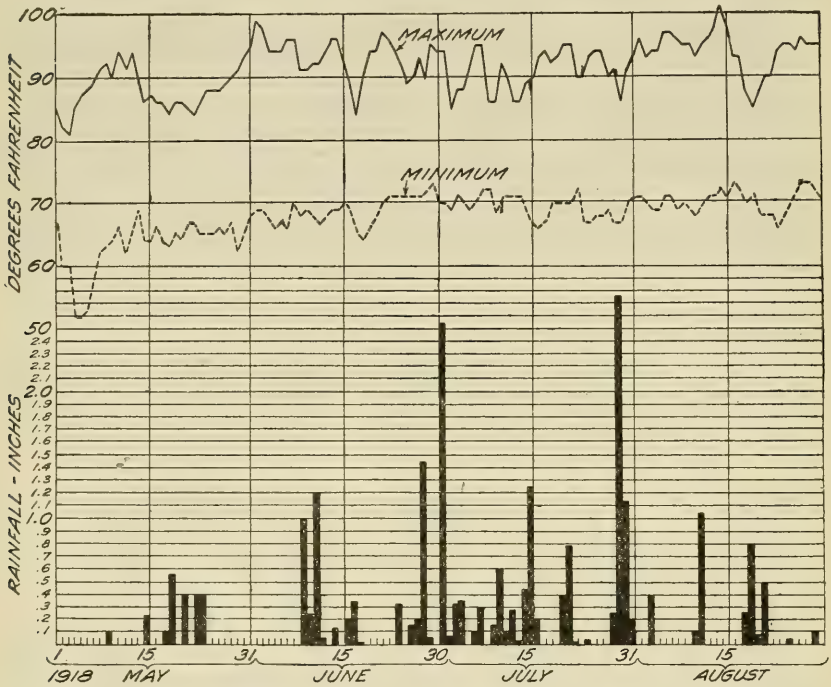

FIG. 5.—Precipitation and maximum and minimum temperatures at Orlando, Fla., during May, June, July, and August, 1918—a period when scab infection was very severe in the nursery.

plete infection doubtless occurred and may account for the irregularity of outbreaks.

Figure 5 gives the temperature range and rainfall at Orlando, Fla., during the months of May, June, July, and August, 1918. Table 4

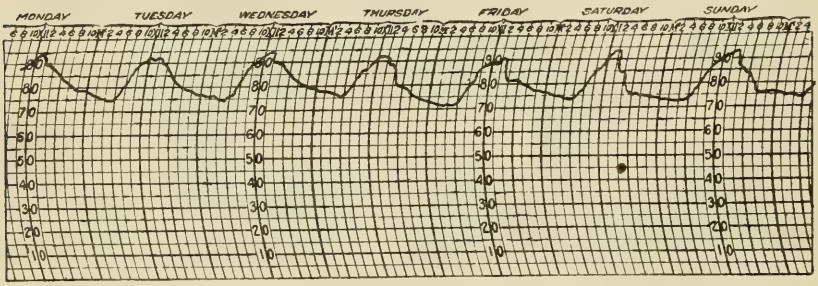

FIG. 6.—Thermographic record of a typical week in summer at Orlando, Fla.

gives similar data for that period of months during 1918, 1919, and 1920, while Figure 6 shows a thermographic record for a representative week.

TABLE 4.—*Mean temperature and precipitation at Orlando, Fla., during the months of May, June, July, and August in the years 1918, 1919, and 1920.*

[Temperature data are stated in degrees F., precipitation data in inches.]

Year.	May.						June.					
	Temperature.				Precipitation.		Temperature.				Precipitation.	
	Extremes.		Mean.	Departure from normal.	Total.	Departure from normal.	Extremes.		Mean.	Departure from normal.	Total.	Departure from normal.
	Maximum.	Minimum.					Maximum.	Minimum.				
1918	87.9	63.1	75.5	−1.4	2.11	−1.7	93.2	68.8	81.0	+0.6	5.37	−1.89
1919	89.3	63.2	76.2	−.7	10.37	+6.56	90.5	68.3	79.4	−1.0	5.19	−2.07
1920	84.3	60.8	72.6	+1.6	6.72	+4.70	91.2	67.8	79.5	−.9	5.89	−1.27

Year.	July.						August.						For 4 months.		
	Temperature.				Precipitation.		Temperature.				Precipitation.		Departure from normal.		Mean temperature.
	Extremes.		Mean.	Departure from normal.	Total.	Departure from normal.	Extremes.		Mean.	Departure from normal.	Total.	Departure from normal.	Temperature.	Precipitation.	
	Maximum.	Minimum.					Maximum.	Minimum.							
1918	90.8	69.4	80.1	−0.2	12.3	+5.5	94.1	70.2	82.2	+0.1	3.34	−3.81	−0.9	−1.9	79.7
1919	92.4	70.3	81.4	−.7	11.49	+4.24	94.3	70.5	82.4	+.3	5.49	−1.69	−2.1	+6.04	79.8
1920	92.7	70.4	81.6	−.5	7.49	+.24	93.3	69.6	81.4	−.7	5.35	+1.8	−.5	+5.37	78.77

It will be noted that in spite of the fact that the mean temperature is in general well above the limits set by Fawcett, the mean minimum temperatures for summer are usually well within that range, but it is probable the temperature does not remain in that lower zone sufficiently long for infection to progress at a rapid rate.

If it is assumed that the pathogen is present in quantity, there are three other factors which play their parts in completing infection, viz, (1) suitable temperature limits, (2) abundant moisture, and (3) host parts in a stage of development susceptible to infection. The relative scarcity of citrus scab in both orchards and nurseries situated in the drier sections of Florida and in the drier seasons, together with the fact that citrus scab has not been able to establish itself in California lemon orchards with their drier climatic conditions, is strong evidence that this fungus is largely dependent upon certain weather conditions to cause infection, namely, abundant moisture during the period when leaves are expanding and fruit is setting. Such weather seldom occurs in the relatively dry citrus regions of California at times when the plant is susceptible to infection; hence, the absence of scab and its resulting financial

losses. Under Florida conditions the normal temperatures occurring throughout the growing months seem to be suitable for infection and for the most part enough moisture is present to allow infection of very susceptible species. Unless the host is in the proper stage of development when there is an abundance of moisture, natural infection does not occur; hence, for practical purposes, it is reasonable to conclude that under average Florida conditions moisture rather than temperature is the important limiting factor in natural infection.

GROWTH HABITS OF GRAPEFRUIT.

A brief consideration of the habits of growth of grapefruit trees under Florida conditions, together with an account of climatic conditions occurring during the periods that a tree is susceptible to infection by the scab fungus, will no doubt aid materially in establishing a reasonable explanation of the behavior of the disease in nature.

Bearing grapefruit trees in the neighborhood of Orlando, Fla., normally produce three distinct flushes of growth during the year. The first growth comes out relatively slowly but uniformly over the tree, usually during February, but in the southern part of Florida it may be as early as January and considerably later at more northern points. The emerging of blossom buds may be the first signs of growth, or vegetative growth and blossom buds may come out simultaneously, or vegetative flushes may partially harden and then develop blossoms on this new wood (Pl. I, Fig. 1).

If the weather is warm and conducive to the active growth of citrus trees there is a comparatively short time between the first signs of growth and the falling of petals from the latest blossoms, but if the weather is cold, rainy, and otherwise unfavorable for growth the vegetative parts emerge very slowly, and the blossoming period alone may extend over more than six weeks. Usually the greater part of the crop develops from this spring bloom.

The second flush comes out very rapidly, usually during the hot dry weather of May several weeks in advance of the rainy season, and in a few days the leaves reach a width of an inch or more. This flush is much less evenly distributed over the tree and is rather irregular in beginning growth. There occurs at this time or somewhat later a small quantity of bloom from which develops the June bloom fruit, which is quite inferior in quality. The so-called "June bloom" is relatively insignificant in quantity. It occurs practically only on trees with little or no fruit resulting from the spring bloom, or following a drought, or on trees which have some root or trunk disease.

The third flush usually starts growing in September, well after the rainy season has passed. The quantity and character of growth is essentially the same as that occurring in May, but seldom accom-

panied by blossoms. Between these main flushes an occasional but irregular putting out of vegetative parts is observed.

In young groves which have not come into bearing the vegetative growth is quite comparable with that occurring in bearing trees, the chief difference being in the number of flushes. Vigorous young trees which are being forced by fertilizers and cultivation are likely to put on five or six distinct flushes during the first year after setting, these decreasing in number until the tree begins bearing a fair crop of fruit. After that time there are usually only three main flushes during the year.

Nursery trees, both budded and seedlings, are continually sending out successive vegetative growths from early spring until late fall, frequently making an extension of as much as 60 inches during the year. Rough lemons especially have emerging leaves present practically throughout the entire growing season, while the sour orange is inclined to be more regular in its growths, the more vigorous plants putting on about 10 flushes.

DISEASE AS INFLUENCED BY THE STOCK.

There is a widespread popular impression that grapefruit growing on rough-lemon roots is more susceptible to scab than when the same variety is grown on sour-orange or grapefruit stock under the same environmental conditions—that the stock lessens the resistance of the scion to this disease.

In general, scions on rough-lemon stock produce a much greater vegetative growth during the first few years than is the case with other popular root systems. Such being the case, trees on these roots have many more leaves and perhaps a greater number of fruits passing through the stages of growth susceptible to infection. Under these actual conditions there is a considerable increase in the chances for trees on rough-lemon roots to become infected even where resistance remains constant. If the stock exerts an appreciable influence on the inherent susceptibility to scab it should show up at least occasionally in inoculation experiments.

A critical study of the results from inoculation experiments conducted during the past five years, coupled with the summary of general orchard observations made over the same period, indicate that there is no material difference in percentage or degree of infection that could reasonably be attributed to immunizing or sensitizing influences produced by the stock on the scion.

ADAPTATION OF THE FUNGUS.

That citrus scab will eventually be as serious on the round orange as it now is on grapefruit is the belief of a large number of practical horticulturists and a few pathologists (*23*). This opinion is based

on the widespread impression that for a number of years this disease was confined to the sour orange and rough lemon, later "adapted" itself to grapefruit, and still later to the round orange. This alleged adaptation on the part of the scab fungus has been explained in several ways. Some claim the grapefruit and round orange, as a result of cultural practices, are rapidly losing their original immunity; others are of the opinion that the scab fungus is gradually adapting itself to the more resistant species; still others would explain the condition on the ground that very virulent strains of the causal organism capable of infecting grapefruit and orange have resulted as natural mutations; and a few do no more than make the prediction that within a short time the orange will be as seriously affected as is now the case with grapefruit.

In the case of citrus scab there appears to be no sound basis for such claims in spite of the fact that such a phenomenon has been noted for other pathogens. Within a few years after citrus scab was first recorded in America, Underwood (*30*) reported the commercial species as being susceptible to infection in essentially the same proportion as is the case to-day. His report was made before the grapefruit as a fruit, or rough lemon as a root stock, began to attract very much attention from commercial growers. Since then these species have gained a great deal of popularity, resulting in the setting out of millions of trees susceptible to infection from scab. This has increased immeasurably the number of foci of infection and also the mathematical chance for infection of all species.

If the scab fungus is adapting itself to the more resistant species, this transition is going on very slowly, so much so that it can not be measured even when viewed over a period of 30 years. The causal organism isolated from round orange, grapefruit, and avocado has shown itself by actual inoculation tests to be neither more nor less pathogenic to grapefruit than was the same organism isolated from sour orange and grapefruit. Cultural studies of the causal organism isolated from various hosts also failed to reveal any difference in the fungus, and field studies over a period of five years fail to give the slightest indication that the round orange is losing its original resistance. There is no valid reason for presuming that at least within the life of trees now planted the orange will be as susceptible to infection as is grapefruit at present. There is no evidence that an inherently more virulent strain of the scab fungus is developing.

INOCULATION EXPERIMENTS.

In order to determine accurately the period of development during which fruit and foliage are likely to become infected and the relative susceptibilities of some citrus species to scab, a rather extensive series of inoculation experiments was conducted on young

citrus trees growing on the laboratory grounds at Orlando, Fla., and in a near-by bearing grapefruit grove. In addition, a limited number of tests were made in bearing groves at other points.

The inoculum used in these experiments was from pure cultures of the scab fungus isolated from the several highly susceptible citrus species, from the resistant sweet orange, and from the avocado, as well as from cultures received from Porto Rico. More complete data relative to the source of cultures are given in Table 5.

TABLE 5.—*Sources of cultures of the citrus-scab fungus used in inoculation tests.*

Host.	Part.	Isolated by—	Date.	From—
Grapefruit	Leaf	J. A. Stevenson	1917	Porto Rico.
Rough lemon	do	H. E. Stevens	1916	Florida Experiment Station.
Rough lemon (?)	(?)	(?)	(?)	H. S. Fawcett.
Grapefruit	Leaf	Fruit-disease investigations.	1916	Orlando, Fla.
Do	Old fallen leaf	do	Jan. 5, 1917	Do.
Do	do	do	Feb. 15, 1917	Do.
Do	do	do	do	Do.
Do	Dried fallen leaves.	do	do	Do.
Do	Fruit	do	May 20, 1917	Do.
Do	do	do	March, 1919	Winter Park, Fla.
Sour orange	Leaf	do	December, 1918	Orlando, Fla.
Do	Fruit	do	April, 1919	Do.
Sweet orange (Ruby Blood).	Leaf	do	December, 1916	Tavares, Fla.
Sweet orange (Pineapple).	do	do	January, 1917	Orlando, Fla.
Satsuma orange	Fruit	do	July, 1916	Thomasville, Ga.
King orange	Leaf	do	February, 1917	Winter Garden, Fla.
Tangerine	do	do	April, 1917	Do.
Tangelo	do	do	March, 1919	Orlando, Fla.
Calamondin	do	do	March, 1920	Do.
Sweet bittersweet	do	do	November, 1919	Do.
Sour Rangpur	do	do	do	Do.
Avocado	do	do	April, 1918	Homestead, Fla.

In general the cultures were grown on potato-dextrose agar for about three weeks before being used as inoculum. A liberal quantity of the vegetative fungus was placed on wet absorbent cotton wads (Pl. XV, Fig. 2). These plasters were so placed that the fungus was in contact with the part to be infected, and they were then covered with several layers of paraffin paper (Pl. XVI), except that in special cases the plasters were left in contact with the parts to be infected for at least 24 hours. Frequently in cool weather the plasters were on 48 hours. At the expiration of this time the paper and moist cotton plasters were removed, and the inoculated parts left unprotected. During the progress of the work, control tests were made by similar methods, except that the inoculum was not used.

Lesions resulting from artificial infections (Pl. I, Fig. 3) developed in from 5 to 10 days after the inoculation was made, but in every case final observations were deferred 15 days or more after the plasters were removed.

Table 6 gives the results of artifical inoculations of fruits of grapefruit, Satsuma orange, and Dancy tangerine with the citrus-scab fungus, and Table 7 gives similar results on leaves of a number of susceptible species. Numerous inoculations were attempted on sweet oranges, but without exception they gave negative results. Because of space limitation these tests are not here reported in detail.

TABLE 6.—*Results of inoculations with the scab fungus on grapefruit, Satsuma orange, and Dancy tangerine fruits.*

Date.	Size of fruit (in sixteenths of an inch).	Total inoculations.	Dropped or lost.	Fruits remaining.	Total positive.	Total negative.	Percentage positive.	Degrees of infection.
Grapefruit:								
Apr. 17, 1917	4	6	0	6	6	0	100	Very severe.
Apr. 10, 1920	4	58	9	49	48	1	98	Do.
Do	4 to 5	31	6	25	23	2	92	Do.
Apr. 19, 1920	4 to 8	230	65	165	129	36	78	Do.
Do	4 to 8	46	9	37	4	33	10.8	33 Royal, no scab; 4 Foster, badly scabbed.
Apr. 20, 1917	4 to 12	16	6	10	5	5	50	Very severe on small fruits.
May 2, 1917	2 to 20	20	1	19	11	8	58	Infection mostly on smallest fruits.
May 9, 1917	4 to 20	16	2	14	11	3	79	Do.
Apr. 23, 1920	5	50	20	30	29	1	97	Moderate.
May 27, 1920	6 to 8	36	22	14	13	1	93	Severe.
Apr. 3, 1919	6	102	49	53	53	0	100	Do.
Apr. 20, 1918	6 to 8	38	9	29	23	6	79	Severe on smallest; moderate on larger fruits.
Apr. 10, 1919	6 to 8	100	33	67	67	0	100	Moderate.
May 27, 1920	6 to 8	36	22	14	13	1	93	Do.
Apr. 27, 1920	6 to 8	36	22	14	13	1	93	Do.
June 4, 1920	6 to 12	40	1	39	9	30	23	Lesions on smaller fruit only.
June 11, 1920	4 to 12	25	6	19	2	17	10.5	Yellow, poor specimens.
May 1, 1917	8	25	2	23	17	6	74	Only a few lesions on each fruit.
May 13, 1920	8	24	5	19	19	0	100	Very severe; Hall (*Silver Cluster*).
Apr. 17, 1919	8 to 10	108	32	76	34	42	45	Infection on smallest fruits only.
Apr. 15, 1918	8	30	10	20	15	5	75	Moderate.
June 17, 1920	14 to 16	15	5	10	0	10	0	
Do	10 to 24	50	20	30	0	30	0	
Apr. 24, 1919	11 to 14	100	29	71	0	71	0	
May 1, 1919	11 to 17	99	41	58	0	58	0	
Apr. 29, 1920	12	48	19	29	6	23	21	One or two small spots on each fruit; Hall variety.
June 11, 1920	12	21	5	16	0	16	0	
May 13, 1920	12	14	6	8	1	7	12.5	Lesions very small; only one or two per fruit.
May 8, 1920	15 to 18	50	15	35	0	35	0	
May 13, 1920	16	12	6	6	0	6	0	
May 8, 9, 1919	1 to 22	100	32	68	0	68	0	
May 13, 1920	1 to 18	7	1	6	0	6	0	
May 15, 1919	1 to 24	100	9	91	0	91	0	
Satsuma orange:								
May 24, 1917	4 to 8	328	157	171	147	24	86	Very severe.
May 8, 1920	5	17	3	14	14	0	100	Severe.
May 31, 1917	10 to 20	100	50	50	3	47	6	Moderate on smallest fruits.
June 4, 1920	6 to 8	18	10	8	7	1	88	Severe.
May 27, 1920	8	5	1	4	4	0	100	Do.
June 11, 1920	8	5	2	3	0	3	0	
Do	8	4	3	1	0	1	0	
June 25, 1920	12	10	2	8	0	8	0	
June 17, 1920	14	10	6	4	0	4	0	
June 25, 1920	16	10	1	9	0	9	0	
Dancy tangerine:								
June 4, 1920	4	24	7	17	13	4	76	Very severe.
June 11, 1920	6	20	15	5	5	0	100	Do.
June 17, 1920	6	25	14	11	11	0	100	Do.
June 25, 1920	6	10	2	8	8	0	100	Do.
Do	6 to 8	10	0	10	9	1	90	Do.

TABLE 7.—*Results of inoculations with the scab fungus on expanding leaves of grapefruit, King and Satsuma oranges, tangerine, lemon, and tangelo.*

Date.	Size, width of leaves (in sixteenths of an inch).	Total inoculations.	Dropped.	Leaves remaining.	Total positive.	Total negative.	Percentage, positive.	Degree of infection.
Grapefruit:								
May 1, 1917	(1)	50	9	41	28	13	68	Very severe.
May 21, 1917	(1)	40	5	35	26	9	74	Do.
Feb. 3, 1919	(1)	16	0	16	16	0	100	Do.
Feb. 19, 1919	(1)	4	3	1	0	1	0	
Feb. 20, 1919	(1)	5	0	5	5	0	100	Do.
Do	(1)	5	4	1	1	0	100	Do.
Do	(1)	4	1	3	3	0	100	Do.
Feb. 28, 1919	(1)	11	0	11	8	3	73	Very severe; 16 hours exposure.
Mar. 3, 1919	(1)	15	2	13	10	3	77	Very severe; 4 hours exposure.
Do	(1)	8	4	4	3	1	75	Very severe; 11 hours exposure.
Do	(1)	7	3	4	3	1	75	Very severe; 6 hours exposure.
Apr. 18, 1919	(1)	10	0	10	0	10	0	Royal grapefruit.
Apr. 22, 1919	(1)	20	4	16	8	8	50	Severe.
Apr. 29, 1919	(1)	13	0	13	13	0	100	Do.
Do	(1)	7	1	6	5	1	84	Do.
Do	(1)	18	2	16	0	16	0	Royal grapefruit.
Apr. 2, 1920	(1)	36	5	31	23	8	74	Severe.
Apr. 5, 1920	(1)	36	5	31	23	8	74	Do.
Apr. 6, 1920	(1)	20	1	19	15	4	79	Do.
Mar. 8, 1919	4 to 64	12	3	9	3	6	33	16 hours exposure.
Mar. 12, 9919	6 to 20	15	0	15	0	15	0	
Mar. 13, 1919	8 to 16	14	0	14	0	14	0	
Apr. 14, 1920	8	39	0	39	0	39	0	
Apr. 10, 1920	8 to 16	23	0	23	0	23	0	
Mar. 8, 1919	8 to 48	9	5	4	0	4	0	Do.
Apr. 10, 1920	8 to 16	20	0	20	0	20	0	Royal grapefruit.
Mar. 12, 1919	8 to 20	10	0	10	0	10	0	
Apr. 16, 1920	12	32	0	32	0	32	0	
King orange:								
Feb. 28, 1920	(1)	10	0	10	9	1	90	Severe.
Apr. 5, 1920	(1)	50	0	50	10	40	20	Moderate.
pr. 20, 1920	4 to 8	61	7	54	0	54	0	
Apr. 16, 1920	8	50	10	40	0	40	0	
Satsuma orange:								
Mar. 26, 1919	(1)	30	4	26	21	5	81	Do.
Mar. 12, 1919	(1)	9	0	9	7	2	78	Do.
Mar. 19, 1919	8	20	5	15	0	15	0	
Mar. 13, 1919	8	4	0	4	0	4	0	
Mar. 12, 1919	8 to 24	8	0	8	0	8	0	
Tangerine:								
Mar. 3, 1919	(1)	5	1	4	4	0	100	Do.
Apr. 10, 1920	8	14	0	14	0	14	0	
Mar. 12, 1919	8 to 16	16	0	16	0	16	0	
Lemon:								
Feb. 19, 1919	(1)	12	4	8	8	0	100	Very severe.
Do	(1)	7	3	4	4	0	100	Do.
Feb. 28, 1919	(1)	4	0	4	4	0	100	16 hours exposure.
Mar. 1, 1919	(1)	4	0	4	4	0	100	Very severe.
Do	(1)	2	0	2	2	0	100	Severe.
Mar. 3, 1920	(1)	2	0	2	2	0	100	Do.
Do	(1)	3	2	1	1	0	100	Do.
Apr. 5, 1920	(1)	5	0	5	4	1	80	Moderate.
Apr. 10, 1920	4 to 8	17	2	15	1	14	7	Very slight.
Apr. 15, 1920	8 to 12	24	4	20	0	20	0	
Mar. 12, 1920	8 to 16	12	0	12	0	12	0	
Mar. 20, 1920	12	20	2	18	0	18	0	
Tangelo:								
Jan. 31, 1919	(1)	4	2	2	2	0	100	Very severe.
Mar. 3, 1919	(1)	25	5	20	20	0	100	Do.
Feb. 28, 1919	(1)	10	0	10	10	0	100	Do.
Feb. 3, 1919	(1)	16	0	16	16	0	100	Do.
June 2, 1920	(1)	20	5	15	12	3	80	Moderate.
June 7, 1920	4 to 8	25	2	23	0	23	0	
Mar. 12, 1919	6 to 16	15	0	15	0	15	0	
Apr. 10, 1920	8 to 16	19	0	19	0	19	0	
Apr. 16, 1920	12	30	4	26	0	26	0	

[1] Expanding.

These inoculation experiments were conducted on properties where more or less citrus scab occurs normally, consequently a small proportion of scab developed in the water checks, but not enough to invalidate the general conclusions from these experiments.

Inoculum from various strains of the citrus-scab fungus was used on each host plant listed. There is no evidence that any one strain of the scab fungus is more virulent than another.

The smallest sizes of citrus fruits in Table 8 represent stages immediately after the falling of the petals. The evidence is that susceptibility is highest at this time and decreases progressively until a diameter of about three-fourths of an inch is reached for grapefruit when they attain immunity.

The leaves of all species tested are found to be most susceptible to infection as they emerge from the bud. They become progressively resistant and reach a stage of immunity when they have developed to one-half inch in width (Pl. VIII, Fig. 2).

The Royal grapefruit, both leaves and fruits, appears to be immune to scab infection.

The scab fungus after growing on artificial media four years is as pathogenic as recently isolated strains.

TABLE 8.—*Water-blank checks on grapefruit, Satsuma orange, and tangerine fruits.*

Date.	Size of fruit (in sixteenths of an inch).	Total inoculations.	Dropped or lost.	Fruits remaining.	Total positive.	Total negative.	Percentage positive.	Degree of infection.
Grapefruit:								
Apr. 10, 1920	4 to 5	19	4	15	4	11	26	Moderate.
Apr. 23, 1920	5	20	7	13	1	12	8	Do.
May 2, 1917	2 to 20	5	0	5	0	5	0	
Apr. 3, 1919	6	40	28	12	3	9	25	Do.
Apr. 10, 1919	6 to 8	40	20	20	0	20	0	
Apr. 20, 1918	6 to 8	20	6	14	2	12	14	Slight.
Apr. 15, 1918	8	25	9	16	2	14	12.5	Do.
May 13, 1920	8	25	5	20	1	19	5	Moderate.
Apr. 17, 1919	8 to 10	40	9	31	4	27	12.9	Slight.
Apr. 19, 1919	8 to 12	39	10	29	0	29	0	Many yellow.
May 9, 1917	8 to 16	30	5	25	4	21	16	Moderate.
June 11, 1920	10 to 24	25	6	19	0	19	0	
Apr. 25, 1919	11 to 14	40	9	31	2	29	6.4	Slight, probably not scab.
May 8, 1920	12 to 16	47	10	37	0	37	0	
May 1, 1919	15	40	11	29	3	26	10.3	Do.
May 8, 1919	17	40	12	28	1	27	3.5	Do.
Apr. 30, 1919	16 to 20	48	20	28	0	28	0	
May 15, 1919	28	40	4	36	0	36	0	
Satsuma orange:								
May 24, 1917	4 to 8	36	11	25	5	20	20	Moderate
June 4, 1920	6 to 8	10	1	9	0	9	0	
May 24, 1917	6 to 8	36	11	25	5	20	20	Slight.
May 17, 1920	8	43	12	31	4	27	13	Do
May 31, 1917	10 to 20	25	18	7	1	6	14	Do.
Tangerine:								
June 4, 1920	4	5	2	3	1	2	33	Moderate.

To determine whether or not *Cladosporium citri* Massee usually found in older scab scars was responsible for the disease, a set of tests parallel with those in Tables 6 and 7 was run. The organisms used in this test were isolated from scab lesions from time to time, grown and applied in a manner similar to that employed in the preceding inoculation tests. The data from these tests, as indicated in Table 9 resulted from inoculations on fruit and leaves of the Satsuma orange and grapefruit.

TABLE 9.—*Results of inoculations of Cladosporium citri on leaves and fruits of grapefruit and Satsuma orange.*

Date.	Part.	Size (in sixteenths of an inch).	Total inoculations.	Dropped.	Remaining.	Total positive.	Total negative.	Percentage positive.	Degree of infection.
Grapefruit:									
Oct. 24, 1917	Leaves	(1)	37	13	24	0	24	0	
Apr. 5, 1918	...do..	(1)	50	26	24	1	23	4	Slight.
May 1, 1918	...do..	(1)	51	29	22	2	20	9	Do.
May 2, 1917	Fruit	4 to 8	50	23	27	2	25	7.4	Do.
Apr. 10, 1918	...do..	6 to 8	40	12	28	2	26	7	Do.
Apr. 22, 1920	...do..	5	48	12	36	3	33	8.3	Do.
May 9, 1917	...do..	8 to 16	46	10	36	5	31	14.	Do.
May 16, 1917	...do..	8 to 24	50	12	38	5	33	13	Do.
Apr. 19, 1919	...do..	12	40	16	24	1	23	4	Do.
May 8, 1920	...do..	12 to 16	50	9	41	0	41	0	
Apr. 30, 1919	...do..	16 to 20	42	7	35	0	35	0	
Satsuma orange:									
May 24, 1917	...do..	4 to 8	52	20	32	3	29	9.3	Do.
June 17, 1920	...do..	8	50	23	27	3	24	11	Do.
June 28, 1920	...do..	12	51	19	32	0	32	0	

[1] Expanding.

It is evident from Table 9 that the Cladosporium found in citrus-scab lesions is not responsible for the disease. The checks in the main show a slightly higher percentage of scab than do the inoculations with Cladosporium organism but not higher than the checks shown in Table 6 for the series of inoculations with the citrus-scab organism.

SPRAYING EXPERIMENTS.

Until recently very little spraying was done in Florida, even on an experimental basis. Growers generally were not inclined to use copper sprays, because such fungicides, while effective against scab, also kill off the entomogenous fungi, resulting in a greatly increased number of insect pests. Unless extra applications of insecticides are made following applications of Bordeaux mixture, the damage resulting from serious scale infection is likely to more than offset the benefits derived from scab control. On the other hand, growers who used lime-sulphur solution claim this material is only partially effective against scab but even then is more desirable for citrus orchard use than Bordeaux mixture.

Similar results were obtained in experimental spraying by Stevenson in Porto Rico (*25*, *26*) and Grossenbacher (*7*), as well as by Florida fruit growers who applied the two materials for test purposes.

The spraying experiments of the writer were interrupted by the freeze of February, 1917, and later by circumstances resulting in part at least from war conditions. During several seasons no scab developed in the orchards where spraying experiments were conducted. Nevertheless, a great many careful studies made of spray schedules employed in commercial groves in Florida and Alabama where scab was successfully controlled, together with the results of inoculation tests and of definite orchard spraying experiments, and of demonstrations, lead the writer to feel confident that the above-mentioned general conclusions are correct and that the disease can be controlled satisfactorily and economically. Good judgment must be used in selecting and applying the fungicide and in following it with insecticides if necessary.

In addition to these field studies and observations, critical spraying experiments were conducted in a nursery of sour-orange and rough-lemon seedlings at Orlando, Fla., during 1919 and 1920. This nursery was set out in the spring of 1918 and was not sprayed that year, resulting in a very general infection on leaves and twigs to serve as sources of early infection the following year.

During the progress of this spraying experiment for citrus-scab control in the nursery the following materials were used:

Formula 1: Bordeaux mixture, 3–3–50, prepared in the usual way.

Formula 2: Bordeaux mixture, 3–3–50, plus 0.5 per cent oil in emulsified form. The Bordeaux mixture was prepared in the usual manner to which sufficient oil emulsion was added to make 0.5 per cent oil in solution.

Formula 3: Bordeaux mixture, 2–2–50, plus 0.5 per cent oil in emulsified form. Prepared in same manner as formula 2.

Formula 4: Bordeaux mixture, 1–1–50, plus 0.5 per cent oil in emulsified form. Prepared in same manner as formula 2.

Formula 5: Commercial Bordeaux paste (6 per cent metallic copper), 12¾ pounds in 50 gallons of water, the equivalent of 3–3–50, plus 0.5 per cent oil in emulsified form.

Formula 6: Homemade Bordeaux paste, in proportions to equal 3–3–50 Bordeaux mixture, plus 0.5 per cent oil in emulsified form.

Formula 7: Burgundy mixture, 3–3½–50, prepared in the usual manner.

Formula 8: Copper soap (Pritchard and Clark's (*16*) formula). Prepared by adding 3 pounds of dissolved resin-fishoil soap to one-half pound bluestone dissolved in 50 gallons of water.

Formula 9: Lime-sulphur solution, 32° B. diluted 1 to 40.

Formula 10: Lime-sulphur solution, 32° B. diluted 1 to 40 plus stabilized oil emulsion, 0.5 per cent.

The oil emulsion used in these spray materials was prepared according to Yothers (*32*, p. 19) by emulsifying 2 gallons of mineral oil with 2 pounds (1 quart) of fishoil soap and 1 gallon of water. To dilute 3 quarts of this emulsion to 50 gallons gives a proportion of 1 per cent oil.

In 1919 the sprays were applied at weekly intervals, beginning in March and continuing throughout the growing season. The applica-

tions were made with a power outfit developing about 300 pounds pressure, and as a rule the sprays were applied with great thoroughness.

The following year the first applications were delayed until a reasonable amount of infection had taken place throughout the nursery, and were made at intervals of 14 days. The same power outfit, pressure, etc., were employed, and the spraying was done as thoroughly as could be expected under commercial conditions. Table 10 shows the results of spraying experiments for the control of citrus scab in a sour-orange and rough-lemon nursery at Orlando, Fla., during 1919 and 1920.

TABLE 10.—*Scab control in the citrus nursery in 1919 and 1920.*

Formula.	Year.	Spray materials used.	Spray injury on foliage or twigs.	Control of scab.
No. 1	1919	Plain Bordeaux mixture, 3–3–50	None	Absolute.
No. 2	1919	Bordeaux mixture, 3–3–50, plus 0.5 per cent oil as emulsion.	do	Do.
No. 7	1919	Burgundy mixture	Russeting of leaves moderate.	Do.
No. 9	1919	Lime-sulphur solution	Defoliation serious.	Moderate, about 50 per cent.
No. 10	1919	Lime-sulphur solution plus 0.5 per cent oil as emulsion.	do	Do.
No. 1	1920	Plain Bordeaux mixture, 3–3–50	None	Absolute.
No. 2	1920	Bordeaux mixture, 3–3–50, plus 0.5 per cent oil as emulsion.	do	Do.
No. 3	1920	Bordeaux mixture, 2–2–50, plus 0.5 per cent oil as emulsion.	do	Do.
No. 4	1920	Bordeaux mixture, 1–1–50, plus 0.5 per cent oil emulsion.	do	Do.
No. 5	1920	Commercial Bordeaux paste plus 0.5 per cent oil as emulsion.	do	Do.
No. 6	1920	Homemade Bordeaux paste	do	Do.
No. 8	1920	Copper soap	do	Do.
Check	1919			Very severe infection, 90 per cent.
Check	1920			Serious infection, somewhat less than 1919, 72 per cent.

At the end of each year 1,000 or more leaves were selected at random and counted for each plat and the presence or absence of citrus scab recorded.

The beneficial results associated with citrus-scab control were very evident during the progress of the work. It was especially noticeable during the spring and early summer of 1919. On June 30, 1919, measurements of growth in height were made over the various plats. At that time and throughout the rainy season of June and July the stunting effect of citrus scab was conspicuous. When the rains stopped and dry weather set in, thereby largely preventing citrus-scab infection, the check plat made a surprisingly rapid growth until checked by cold weather.

The following year citrus scab did not become at all serious until the rainy season set in, and for that reason the stunting effect was not particularly marked.

No spray injury was noted until hot weather set in, then considerable scorching of mature leaves and blighting of tender shoots was usually experienced on plats sprayed with lime-sulphur solution. Defoliation was very serious with the sour orange, but not quite so marked in the case of the rough lemon. Oil emulsion added to the lime-sulphur solution increased the injury by about 20 per cent. Neither material (formulas 9 and 10) gave more than 50 per cent control.

Burgundy mixture (formula 7) produced a slight russeting of foliage, but not in sufficient proportions to be considered serious. Nevertheless, with a slight excess of either the sal soda or the bluestone, considerable damage is likely to occur, and for that reason it appears to be too treacherous to be employed in ordinary nursery work where unskilled labor has to be relied upon to attend to the preparation and application of the sprays. This material gave perfect control of scab.

Copper soap (formula 8) gave very pleasing results. No injury was found on the trees sprayed with this material. This formula carries an excess of soap and apparently is quite safe for use. It controlled scab perfectly.

Plain Bordeaux mixture (formula 1) controlled scab perfectly, and no spray injury resulted. The chief objection to copper sprays, especially Bordeaux or Burgundy mixtures, is that scale insects usually become very numerous following such applications unless drastic measures are taken to prevent these insects from multiplying.

Bordeaux mixture plus oil emulsion (formulas 2, 3, 4, 5, and 6) evolved especially to overcome the objectionable aftereffects of plain Bordeaux mixture, also controlled scab perfectly. It adheres as well as plain Bordeaux mixture and spreads much better. The weaker formulas of Bordeaux mixture gave equally as good results as the stronger materials. Where this combination spray was applied, scale insects were held down satisfactorily without extra sprayings. No injury resulted from the use of any of these formulas.

COMMERCIAL CONTROL.

While the actual control of citrus scab per se by means of sprays is not especially difficult if the spraying is done with thoroughness, at the proper time, and with effective materials, the commercial control of scab on grapefruit presents numerous factors for consideration, some of which are extremely important.

Perhaps the most important single factor, in so far as the well-being of the tree is concerned, is the beneficial or entomogenous

fungi. So effective are these fungi in the control of certain insect pests that there are numerous orchards which bear plentiful crops of excellent fruit without the aid of sprays. About 12 species of entomogenous fungi are recognized in Florida citrus orchards. The earliest forms begin growth about the 1st of May, and the later forms are active until late fall or winter.

It is true that the time for spraying against scab on grapefruit usually has passed before the entomogenous fungi become active. It is also true that any fungicide especially effective in scab control is likely to persist on the sprayed parts for a considerable time after the period of scab infection has passed. Further, any fungicide effective against scab is likely to be very harmful to the entomogenous fungi. Therefore when an effective, lasting spray is applied to control the scab fungus a corresponding control of entomogenous fungi is most likely to occur, and this would result in an enormous increase of insect pests unless drastic measures are taken to check them.

These entomogenous fungi seem to thrive best under local conditions which are especially favorable for citrus scab. For example, in those rather moist localities where natural control of insect pests is most pronounced attacks from citrus scab are usually severe.

Citrus scab tends to vary greatly from year to year and section to section. Even in a given locality it varies a great deal, and the fact that an orchard is affected seriously with citrus scab is by no means strong evidence that the same property will be even lightly affected the following year.

Nevertheless, there are localities where citrus scab is regularly serious, others where the disease is usually moderately prevalent, and still others which are attacked only during years especially favorable for citrus-scab development. For the sake of economy these three types of localities should not have the same spray schedule for the control of citrus scab. A spray program which would list the least number of applications necessary to produce clean fruit in localities where citrus scab is constantly serious would be unnecessarily expensive in time consumed and materials used where the disease occurs only during years especially favorable for scab development.

On the other hand, one or two applications of lime-sulphur solution, though it is a weak, short-lived fungicide, made during the scab season is money well invested, even if scab does not occur, for the reason that such applications practically eliminate red spiders and greatly reduce rust-mite injury.

The judicious selection of the spray material for use in a citrus orchard is by no means an easy task, because all are not equally effective against scab, and certain of them are likely to be followed

by injurious or even disastrous effects from later insect attack. Bordeaux mixture is the most effective spray against scab, and when made up with lake or shallow well (soft) water spray injury seldom follows. Usually deep well (hard) water is satisfactory, but a few instances are on record where a moderate amount of spray burn has resulted from Bordeaux mixture being made up with such water and applied on citrus trees. In certain localities hard water can be used with safety, while in others it is likely to be followed by more or less spray burn. Unless extra applications of insecticides are made, scale insects are very likely to increase rapidly and do great damage following this spray. Commercial Bordeaux preparations (Wallace, *31*) when used in sufficient quantities to give about three-sixteenths of 1 per cent copper in the diluted spray are effective though expensive substitutes for homemade Bordeaux mixture. Bordeaux mixture plus oil emulsion is equally as effective against citrus scab as is plain Bordeaux mixture and against insects as is the same strength of oil emulsion when applied separately. The fungicidal effects outlast the insecticidal effect, and for this reason the usual treatment and sometimes extra applications for scale are required following the use of Bordeaux mixture plus oil emulsion. Burgundy mixture is quite effective against citrus scab, but if not carefully made is likely to cause some injury to fruit or foliage. This spray is considered too risky for general use. Scale insects become very numerous following applications of this material. Ammonical copper carbonate solution is much less effective against citrus scab than is Bordeaux mixture. In general, it is not a desirable spray for scab control. Scale insects increase considerably following its use. Lime-sulphur solution, 32° B., diluted 1 to 40, is not more than 50 per cent effective against severe scab infection, but for certain reasons it can be applied profitably in many orchards. No spray injury has been observed where this material was used during the spring for scab control. This spray kills red spiders, rust mites, and scale crawlers. Dry lime-sulphur and barium sulphur when used on the basis of sulphur equivalents of standard lime-sulphur solution, seem to be fairly satisfactory but quite expensive substitutes for the commercial lime-sulphur solution. Soda-sulphur or sodium-sulphur compounds are expensive and comparatively ineffective substitutes for lime-sulphur solution for use against scab. The hazard of spray burn is especially great following the use of sodium-sulphur compounds of fungicidal strengths.

Dusting for the control of citrus scab has not been tested thoroughly. There seems to be no good reason for assuming that dusting with materials now used will prove as effective or as practical as spraying.

TABLE 11.—*Spray schedules for the control of citrus scab in Florida.*

No. 1.—FOR ORCHARDS WHERE CITRUS SCAB IS ALWAYS SERIOUS.[1]

Application.	Time of application.	Materials used.	Object and remarks.
First	Just before growth sets in.	Bordeaux mixture, 3-3-50, plus 1 per cent oil as emulsion.[2]	To cover old scab lesions. Direct the spray especially toward the under surface of the leaves; reduces very early citrus-scab infection.
Second	In height of bloom	Bordeaux mixture, 3-3-50, plus 0.5 per cent oil as emulsion.[2]	For the protection of expanding leaves and small fruit against scab and melanose.
Third	Two weeks later	do	For the protection of small fruit against scab and melanose.
Fourth	Two weeks after third application.	Bordeaux mixture, 3-3-50, plus 1 per cent oil as emulsion.	Advisable if the season is rainy. For protection against scab; will also reduce early melanose infection.

CAUTION: Insecticidal applications must follow to prevent serious scale injury.

No. 2.—FOR ORCHARDS WHERE CITRUS SCAB VARIES FROM MODERATE TO SERIOUS.[3]

First	Just before growth sets in.	Bordeaux mixture, 3-3-50, plus 1 per cent oil as emulsion.	To cover old scab lesions. Direct the spray especially toward the under surface of the leaves; reduces very early citrus-scab infection.
Second	In height of bloom	Lime-sulphur solution, 1 to 40, or Bordeaux mixture, 3-3-50, plus 0.5 per cent oil as emulsion.	To protect expanding leaves and small fruit from scab and melanose.[4] If the season is normal use lime-sulphur; if the season is rainy use Bordeaux mixture.
Third	Two weeks later	do	To protect small fruit from scab and melanose. If the season is normal use lime-sulphur; if the season is rainy use Bordeaux mixture.
Fourth	Two weeks after third application.	Bordeaux mixture, 3-3-50, plus 1 per cent oil as emulsion.	If the season is rainy, probably advisable for protection of smallest fruits against scab; will also reduce early melanose infection.

No. 3.—FOR ORCHARDS WHERE CITRUS SCAB IS OF MINOR IMPORTANCE.[5]

First	Just before growth sets in.	Lime-sulphur solution, 1 to 30.	To cover the old scab lesions. Direct the spray especially toward the under surface of the leaves; prevents early scab infections.
Second	In height of bloom	Lime-sulphur solution, 1 to 40.	To prevent infections on expanding leaves and small fruit.
Third	Two weeks later	do	To prevent infections on expanding leaves and small fruit. Advisable only when the season is especially favorable for scab development.

[1] To insure bright clean fruit at harvest time follow schedule No. 1 with the regular scale, white-fly, and rust-mite spray applications (see Farmers' Bulletin 933), one or two additional applications of which should be used to check the heavy increase of insect pests following copper sprays.

[2] Prepare 3-3-50 Bordeaux mixture in the usual way. Three quarts of oil emulsion, Government formula, in 50 gallons of Bordeaux mixture gives 1 per cent oil. *Add the oil emulsion to the Bordeaux mixture while the latter is being thoroughly agitated in the spray tank.* Keep up the agitation while spraying.

Preparation of boiled-oil emulsion, Government formula.

[See U. S. Dept. Agr., Farmers' Bulletin 933.]

Paraffin oil	gallons	2
Water	gallon	1
Fishoil soap	pounds	2

Put oil, water, and soap into a kettle or other vessel that will stand fire and heat to the boiling point. While still very hot, but after removal from the fire, pump the material into another vessel with a bucket pump and then pump back again.

[3] To insure clean, bright fruit at harvest time follow schedule No. 2 with regular scale, white-fly, and rust-mite spray applications. When Bordeaux mixture is used additional applications of oil emulsion most likely will be necessary.

[4] Lime-sulphur solution has not proved effective in melanose control.

[5] To insure clean, bright fruit at harvest time follow schedule No. 3 with the regular scale, white-fly, and rust-mite spray applications.

The spray schedules shown in Table 11 are drawn to meet the varying degrees of citrus-scab outbreaks as they occur in Florida orchards. Spray schedule No. 1 should be followed where scab is usually present in serious proportions; spray schedule No. 2 should be followed in localities where citrus scab varies in prevalence from serious to moderate; spray schedule No. 3 should be followed in localities where citrus scab is a minor disease. Because of its effect upon spiders, mites, and insects, schedule No. 3 will prove profitable even if citrus scab does not occur on unsprayed trees.

Nurseries can be kept commercially free from citrus scab by occasional applications of Bordeaux mixture plus oil emulsion. On an average, monthly applications probably will afford adequate protection. In many instances a smaller number of applications will suffice; however, the frequency of applications is dependent upon local and seasonal conditions. Care must be taken to keep new flushes protected during periods of wet weather.

The use of Bordeaux mixture plus oil emulsion was followed by a considerable increase in the growth of grapefruit seedlings even when citrus scab did not occur in the planting. Where citrus scab has occurred on sour-orange and rough-lemon seedlings the increase of growth following applications of Bordeaux mixture plus oil emulsion has been greater than the probable retardation due to scab. These two observations seem to indicate that this spray mixture may act as a growth stimulus in citrus nurseries.

SUMMARY.

Citrus scab, an important disease of foreign introduction, attacks many citrus species. It occurs in India, China, Formosa, Japan, Hawaii, Paraguay, Brazil, Canal Zone, Yucatan, West Indies, Canary Islands, South Africa, and the citrus-growing regions of the Gulf States. As yet it has not become established in California or Arizona.

This disease is second in importance to melanose and stem-end rot caused by *Phomopsis citri*. It is the most serious fungus disease of the citrus nursery, where it attacks leaves and succulent twigs. In the orchard its activity is mainly confined to fruit and leaves.

Leaves are most susceptible in the very early stages of growth. They become entirely resistant by the time they reach half an inch in width.

Young grapefruits are extremely susceptible to infection immediately after the falling of the petals. They become progressively resistant until they reach immunity at a diameter of about three-fourths of an inch.

Scab infections are likely to occur whenever there is sufficient moisture at the time the parts are in a susceptible stage. Under such conditions infections developing in the hot, rainy summer months

are as severe as those occurring during the cool weather of spring or fall.

Citrus scab is caused by a definite fungus usually but erroneously referred to as *Cladosporium citri* Massee. It has none of the characters of Cladosporium Link. It has been confused with a common saprophyte in citrus lesions.

The causal fungus does not live over winter on mature fruit. It passes this period on affected leaves which act as foci of infection the following spring.

The citrus-scab fungus does not appear to be more virulent now than was the case a few years after its first introduction into America, nor are the various citrus varieties changing their former susceptibility.

There is no material difference in percentage or degree of infection that could reasonably be attributed to immunizing or sensitizing influences produced by the root stock on the scion.

Cumulative evidence including spraying experiments and orchard observations, goes to show that citrus scab can be controlled satisfactorily and economically. Scab in the nursery can be controlled readily by occasional applications of effective sprays.

Plain Bordeaux mixture as well as Bordeaux mixture plus oil emulsion is very effective against citrus scab, either in the nursery or in the orchard. Burgundy mixture is distinctly less effective than Bordeaux mixture, and ammonical copper carbonate solution is much less so.

Lime-sulphur solution is much less effective against this disease than is Bordeaux mixture. The other sulphur sprays are no more effective against citrus scab than is lime-sulphur solution.

Spraying after the smallest fruits have attained a diameter of three-fourths of an inch has no effect on the control of scab.

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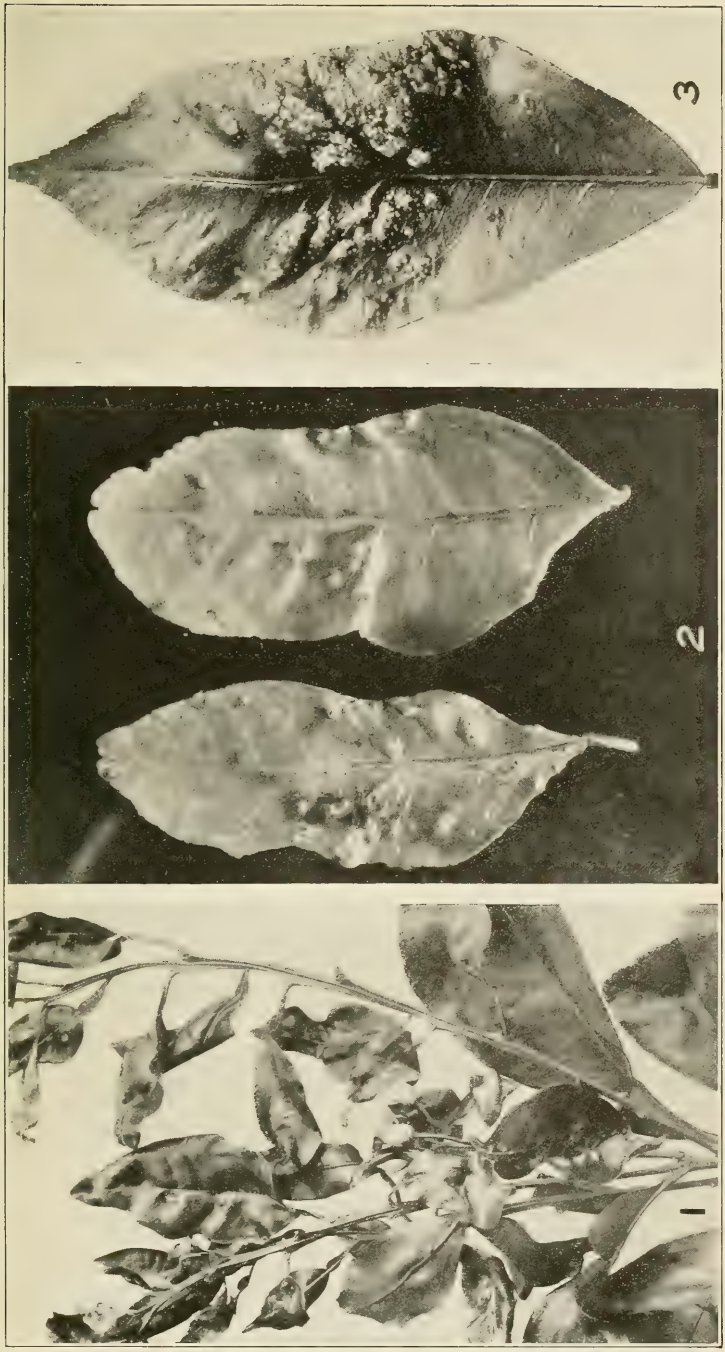


CITRUS SCAB ON THE LEAVES OF GRAPEFRUIT, SATSUMA ORANGE, AND LEMON.

FIG. 1.—New flush of growth on grapefruit affected with scab. Blossoms have developed. (Photographed by Grossenbacher.) FIG. 2.—Effects of a moderate infection on leaves of the Satsuma orange. This disease is usually not especially conspicuous on the leaves of this variety. FIG. 3.—Citrus-scab lesions resulting from artificial inoculation on a lemon leaf.

CITRUS SCAB ON GRAPEFRUIT LEAVES.

Distortion of the leaves is very frequently associated with scab infection.

FIG. 1.—CITRUS SCAB ON HALL GRAPEFRUIT.

Fruits distorted to this extent usually drop in May or June. Should they reach maturity they would be graded as culls.

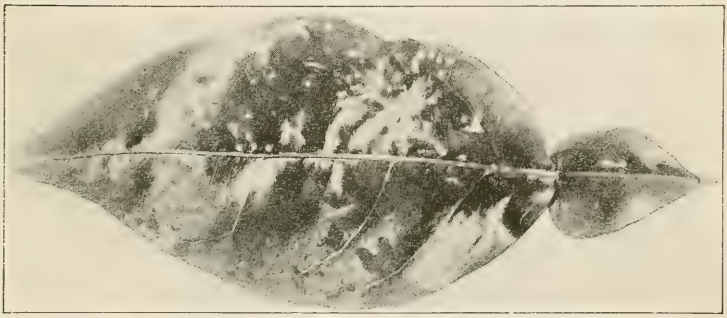


FIG. 2.—CITRUS SCAB ON LEAF OF GRAPEFRUIT.

Effects of artificial inoculations with the citrus-scab fungus.

CITRUS SCAB ON SOUR-ORANGE NURSERY STOCK.

The difference in size of these plants is due largely, if not solely, to the stunting effects of this disease.

FIG. 1.—CITRUS SCAB ON A SATSUMA ORANGE.

This is probably the most serious parasitic disease of this variety.

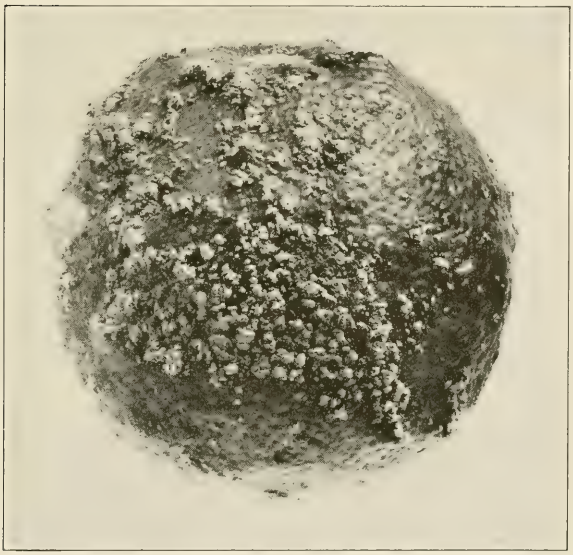
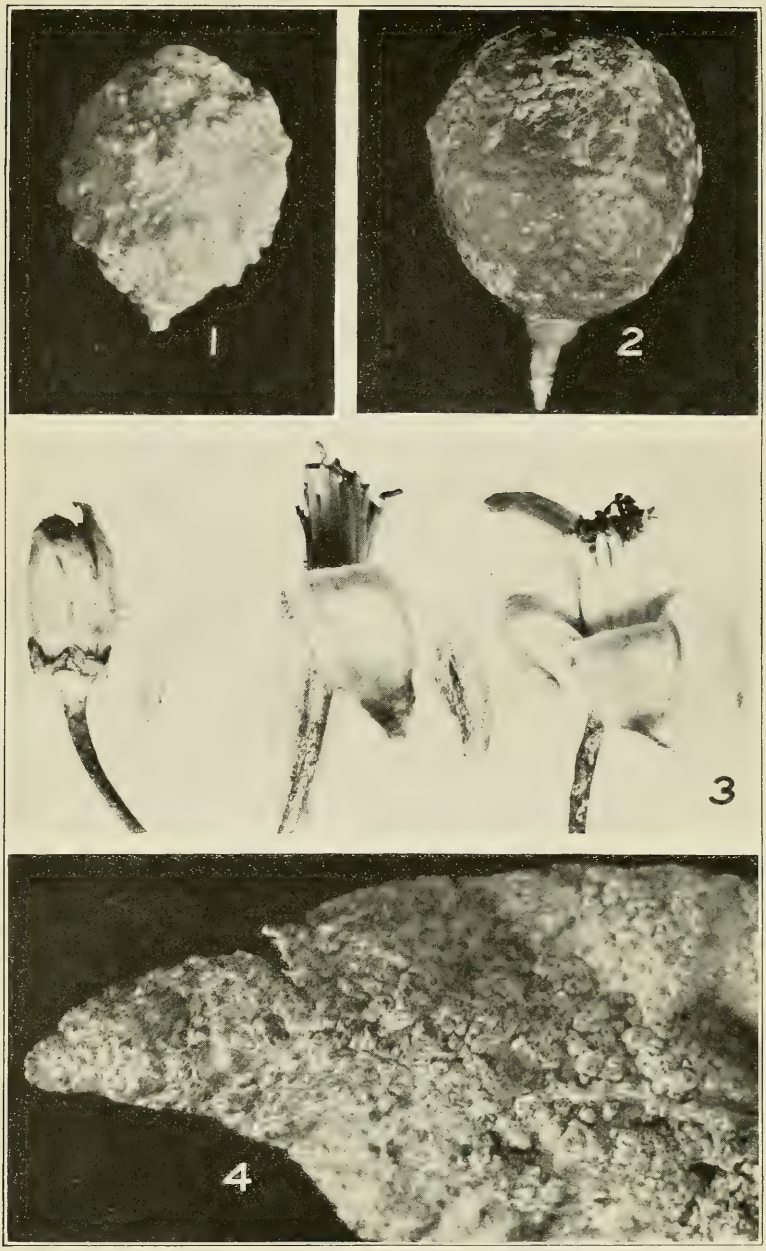


FIG. 2.—CITRUS SCAB ON A SOUR ORANGE.

The sour orange is of considerable economic importance. It is admirably adapted as a stock for heavy soils, and its fruit makes an excellent ade as well as a base for jellies, marmalades, etc.



CITRUS SCAB ON TANGELO, LEMON, GRAPEFRUIT, AND SOUR ORANGE.

FIG. 1.—Very severe attack of scab on tangelo. This fruit probably would not have reached maturity. (Natural size.) FIG. 2.—Characteristic scab lesions in immature lemon. (Natural size.) FIG. 3.—Lesions on stem and calyx of grapefruit flowers. FIG. 4.—Scab lesions on mature sour-orange leaf. × 3.

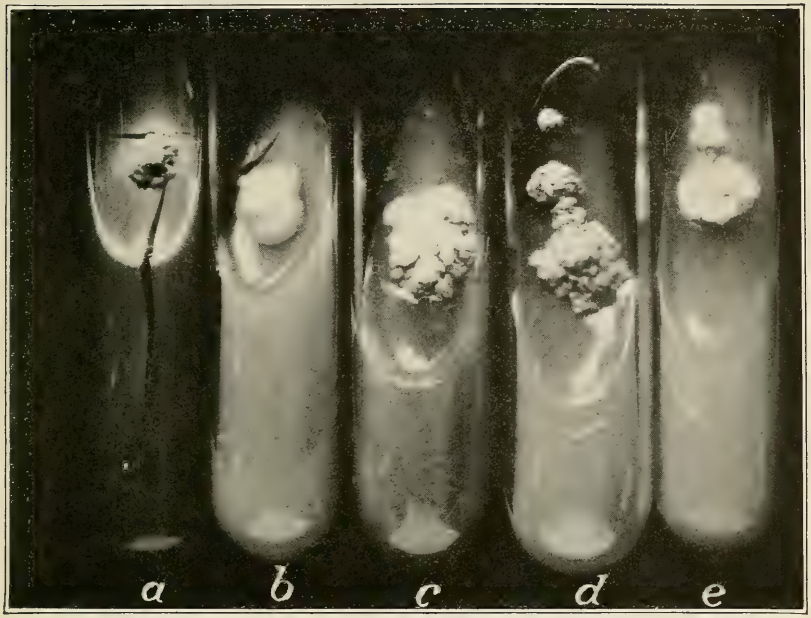


FIG. 1.—CULTURES OF THE CITRUS-SCAB FUNGUS.

Growth of 16 days on slants: *a*, On beef agar; *b*, on glycerin agar; *c*, on potato-dextrose agar; *d*, on Molisch's agar; *e*, on tomato agar. This fungus varies greatly in culture. The growth characters in tubes *b* and *d* are not at all similar.

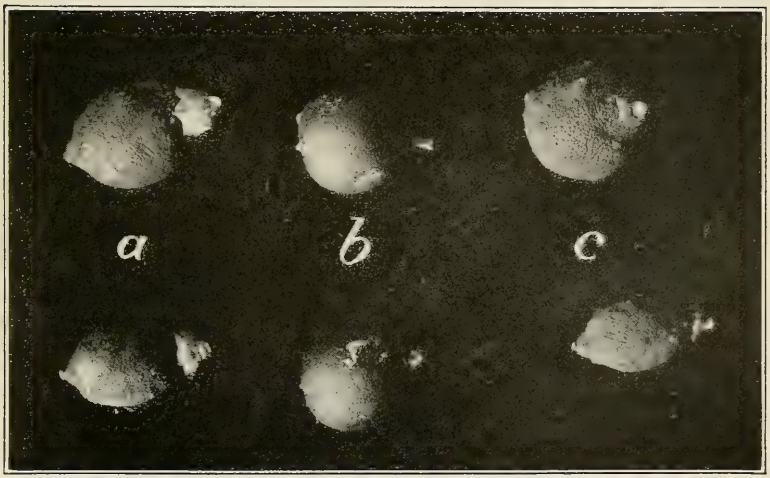


FIG. 2.—CITRUS SCAB ON UNUSUAL CITRUS FRUITS.

Effect on Chinese lemon (*a*); calamondin (*b*); Sour Rangpur lime (*c*).

FIG. 1.—CITRUS SCAB ON LEAVES AND STEM OF ROUGH-LEMON NURSERY STOCK.

This disease produces a severe stunting effect on small seedlings of susceptible species.

FIG. 2.—EXPANDING GRAPEFRUIT LEAVES.

On the left, the leaves are in the stage of growth most susceptible to scab; on the right, the larger leaves are no longer susceptible to infection. (Slightly reduced.)

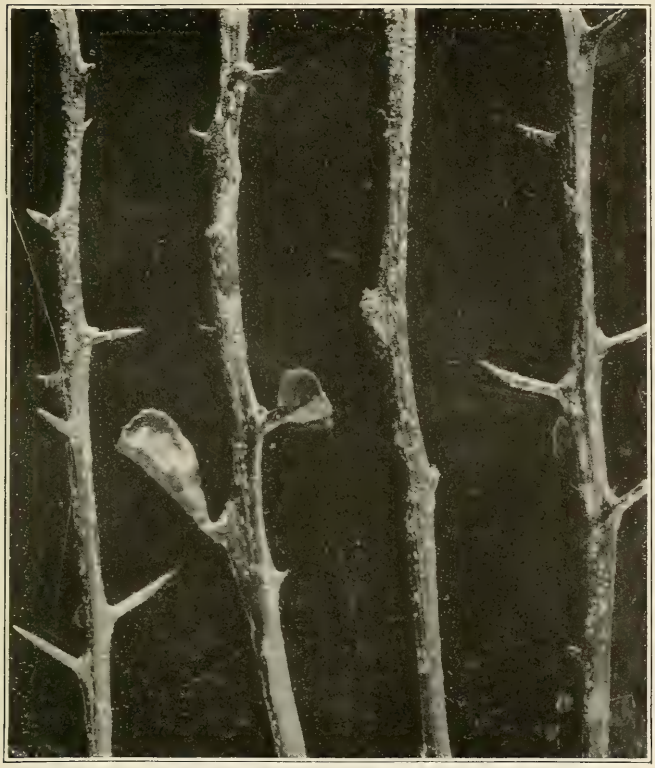


FIG. 1.—TWIGS OF SOUR ORANGE AFFECTED WITH CITRUS SCAB.

These infections took place in southern Florida during the summer of 1920.

FIG. 2.—CITRUS SCAB ON THE LEAVES OF SOUR ORANGE.

These leaves expanded and became infected in the Government nursery at Orlando, Fla., during the summer of 1920.

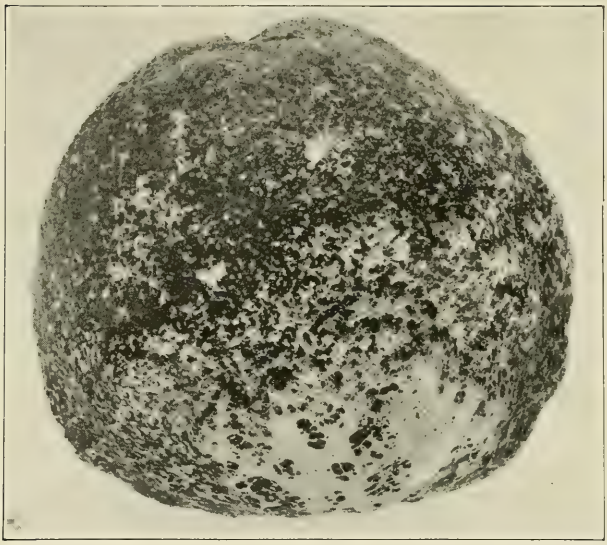
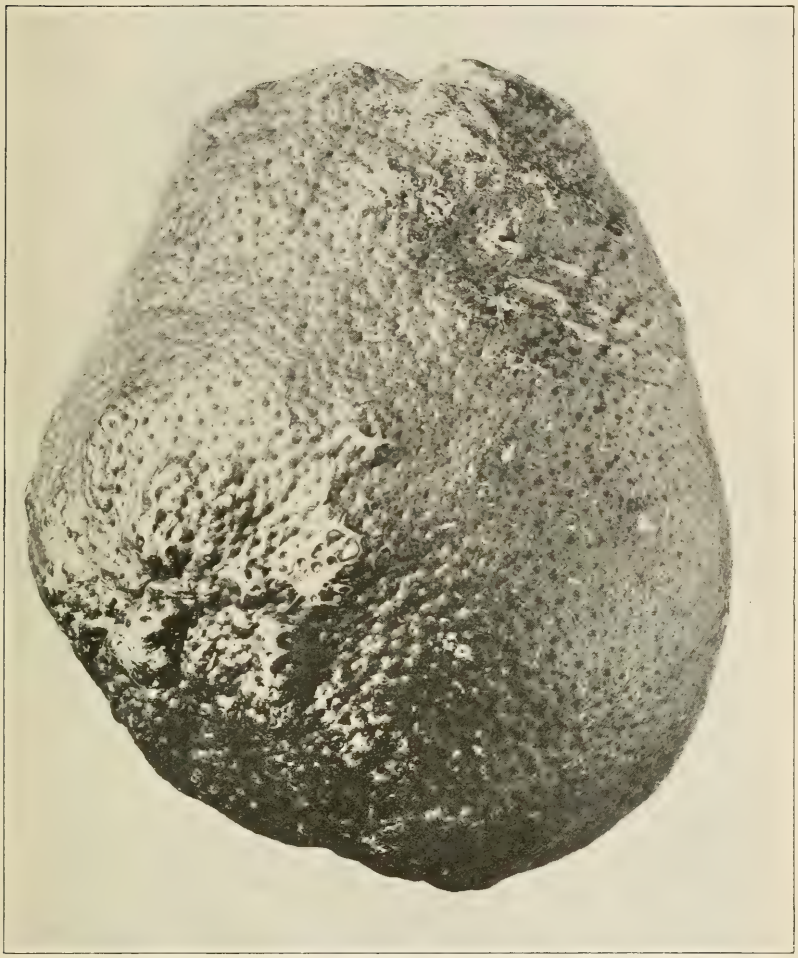


FIG. 1.—CITRUS SCAB ON IMMATURE GRAPEFRUIT.

Effects of a severe, general infection which occurred when the fruit was very young. (Natural size.) Note that the protuberances have flattened considerably. Such fruits usually fall before reaching maturity.

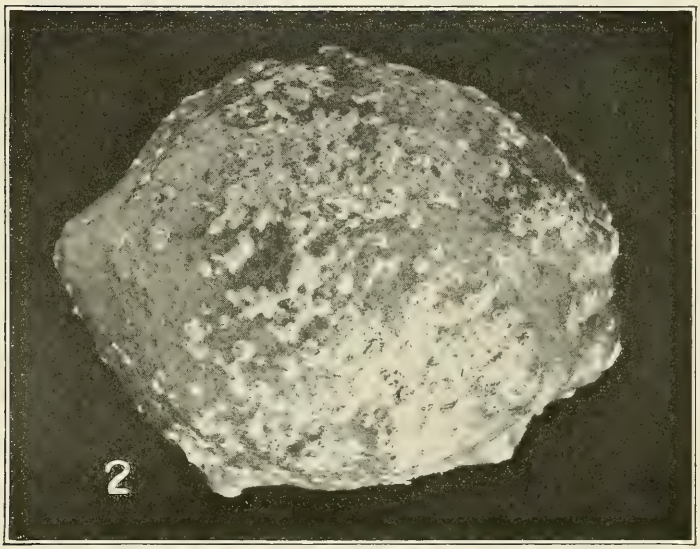
FIG. 2.—CITRUS SCAB ON GRAPEFRUIT.

Effects of a late infection on fruit which reached maturity.



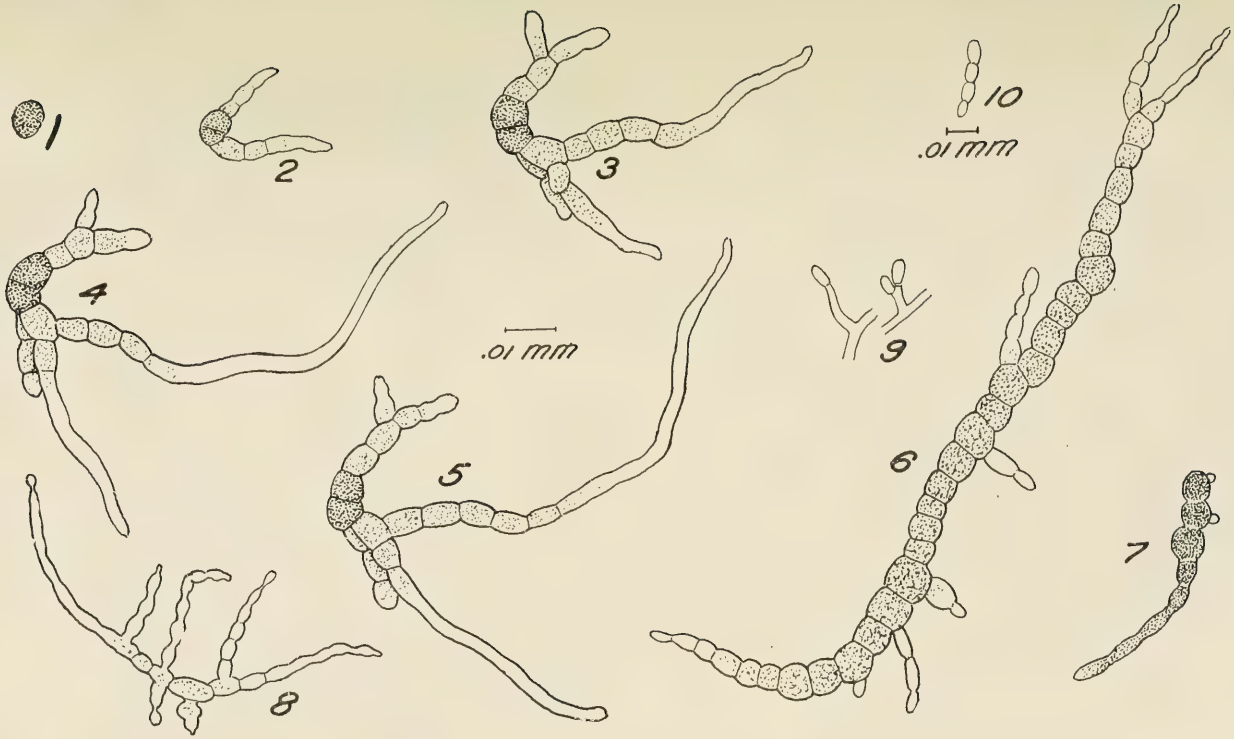
CITRUS SCAB ON GRAPEFRUIT SET IN JUNE.

Fruit set in June or during the rainy season usually becomes scabby, pear shaped, and is at best poor in quality. When such fruit is attacked by citrus scab the lesions do not flatten out as completely as is the case with spring-bloom fruit.



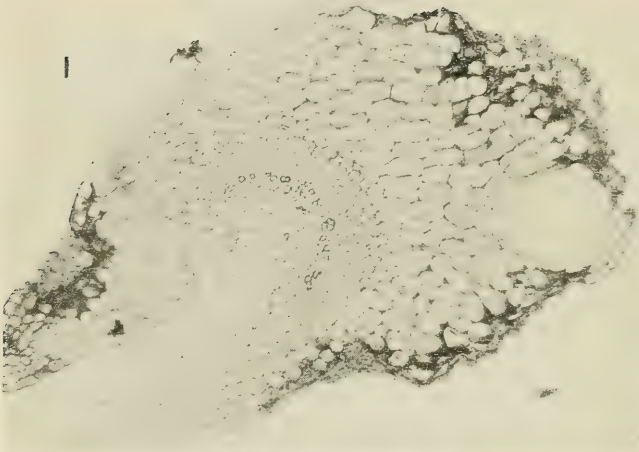
CITRUS SCAB ON TANGELO AND LEMON VARIETIES.

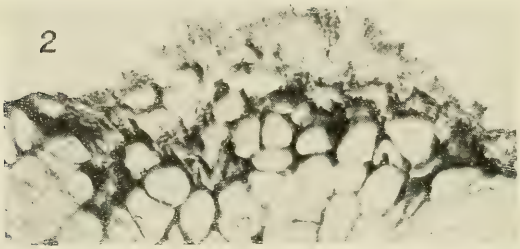
FIG. 1.—Effect on a mature Sampson tangelo. FIG. 2.—Effect on Eureka lemon. These species are extremely susceptible to this disease, which detracts largely from their value for commercial plantings.

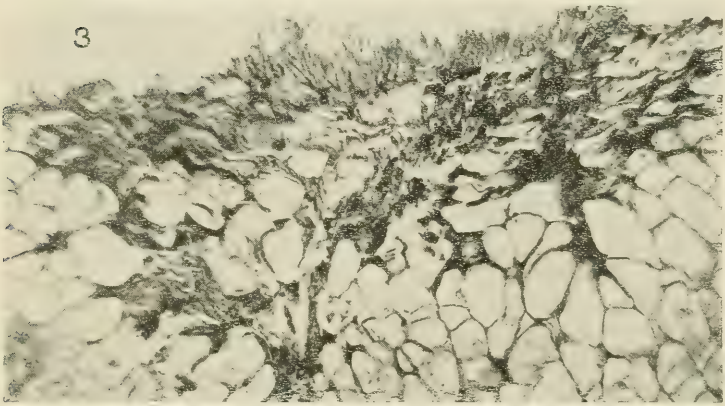


GROWTH CHARACTERS OF THE CITRUS-SCAB FUNGUS.

FIG. 1.—Chlamydospore of the citrus-scab fungus. FIG. 2.—Growth from chlamydospore after 24 hours at 20° C. FIG. 3.—Growth from chlamydospore after two days at 20° C. FIG. 4.—Growth from chlamydospore after three days at 20° C. FIG. 5.—Growth from chlamydospore after six days at 20° C. FIGS. 6 AND 7.—Germinating chlamydospores. FIG. 8.—Germination from comparatively young constricted mycelium after 48 hours at 20° C. FIG. 9.—Conidia of the citrus-scab fungus, grown on corn-meal agar by Miss Anna E. Jenkins, of the Office of Pathological Collections. FIG. 10.—Constricted young mycelium.







CITRUS SCAB ON THE LEAVES OF ROUGH LEMON.

FIG. 1.—Photomicrograph of cross section of emerging leaf infected with citrus scab. Three distinct lesions are seen on the lower or exposed surface. The arrangement of the leaf in the bud probably accounts for the relatively small number of lesions found on the upper surface of affected leaves. FIG. 2.—Photomicrograph of citrus-scab lesion on expanding leaf. Such lesions can sometimes be seen faintly with the unaided eye. The leaf tissue is affected to a depth of two or three cells, even before the leaf expands. Notice the stromatic mass of fungal hyphæ. FIG. 3.—Photomicrograph of a citrus-scab lesion on expanded leaf. This lesion, probably 2 months old, is being overrun by a saprophytic Cladosporium. The scab fungus penetrates the host tissue intercellularly for some distance.

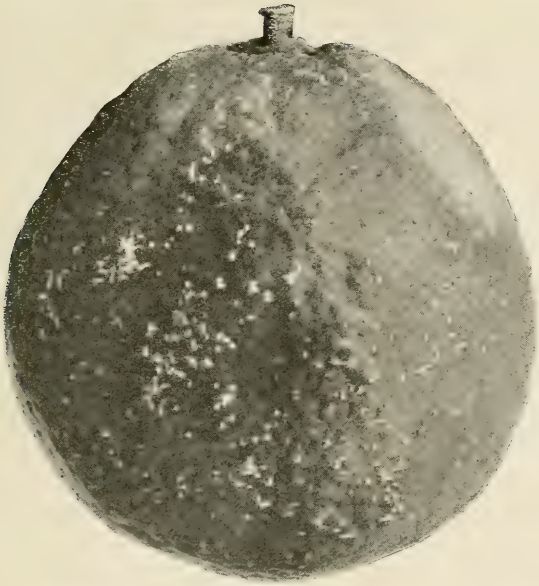


FIG. 1.—EFFECT OF ARTIFICIAL INOCULATION WITH THE CITRUS-SCAB FUNGUS ON GRAPEFRUIT.

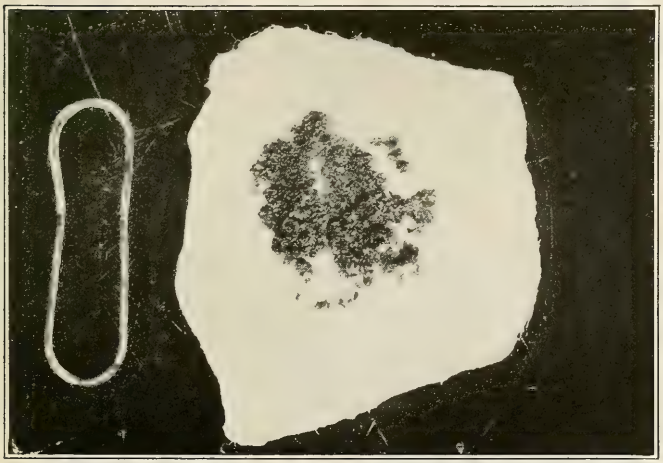


FIG. 2.—COTTON PAD AND INOCULUM SMEAR USED IN MOST INOCULATION EXPERIMENTS.

FIG. 1.—A KING OF SIAM TREE WITH WRAPPED INOCULATIONS AFTER WEATHERING A 2-DAY STORM.

This method of making inoculations has proved very satisfactory for outdoor work.

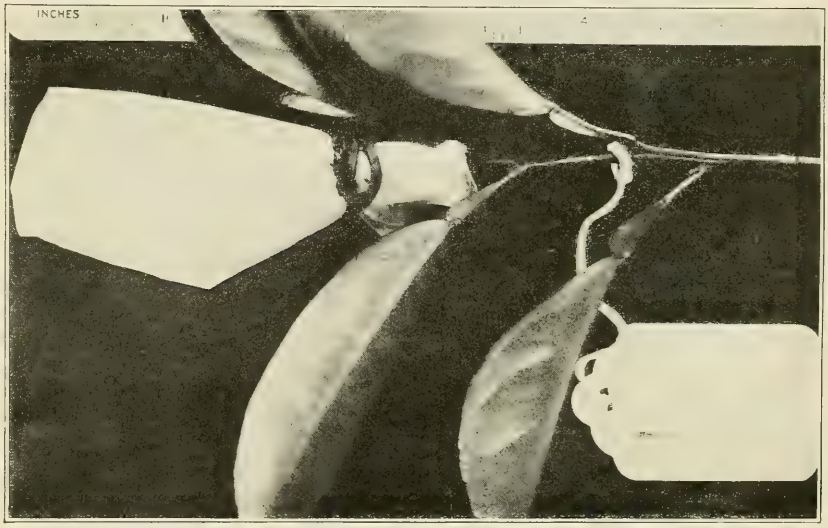
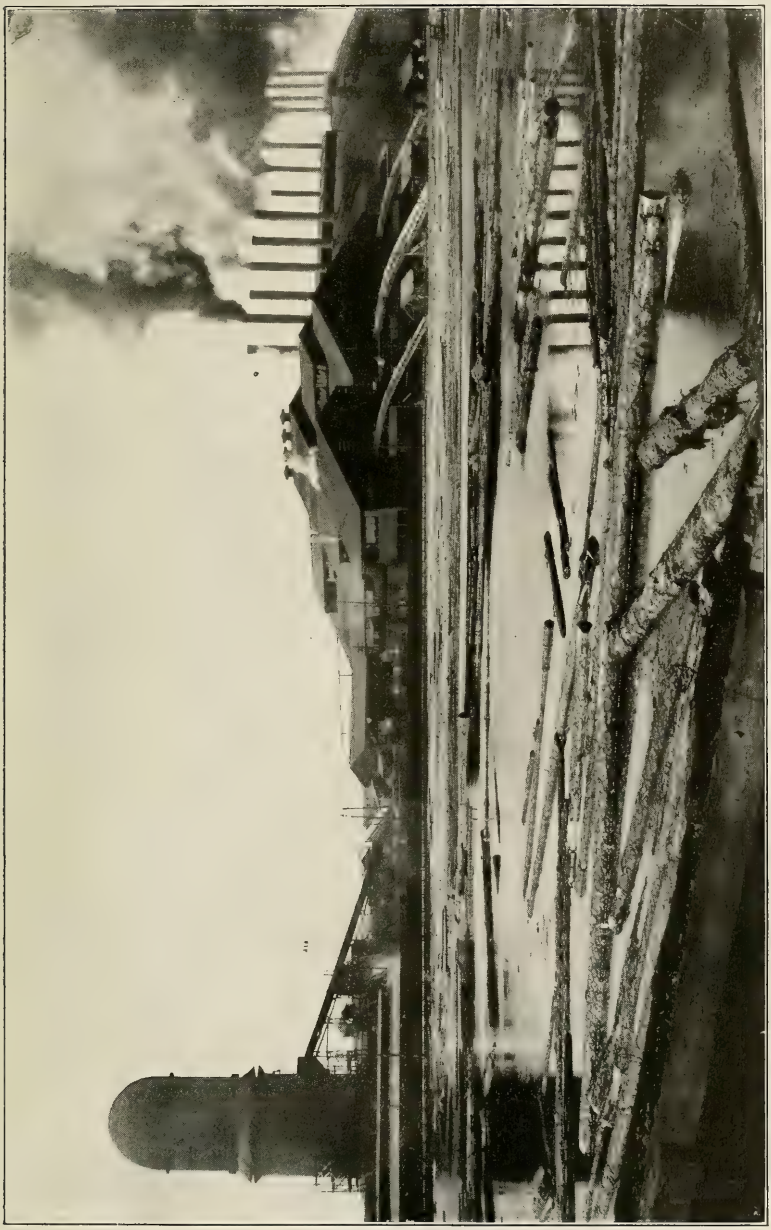


FIG. 2.—A WRAPPED INOCULATION.



CLASS 5 SAWMILL.

This enormous plant has cut as much as 1,000,000 feet of lumber per day, which is the equivalent of 50 to 300 acres of forest. In Class 5 are less than 4 per cent of our mills, but the class produces nearly 60 per cent of the total cut. (See Tables 2 and 3.)

CLASS I SAWMILL.

Mills of this class are mainly portable, and their average cut is about 200,000 feet a year. As the big mills finish their cut the small mills clear up the more scattered and less accessible timber, and work in second growth. Class I contains nearly 70 per cent of the mills, but produces only 10 per cent of the cut.

UNITED STATES DEPARTMENT OF AGRICULTURE

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LUMBER CUT OF THE UNITED STATES, 1870-1920.

By R. V. Reynolds, *Forest Examiner*, and
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INTRODUCTION.

This report, so far as it relates to lumber production in 1920, is the latest of a series that had previously covered the period 1904 to 1918, inclusive, with the exception of 1914.[1] It is of wider scope than the rest of the series, for it contains not merely detailed statistics of the 1920 production of lumber, lath, and shingles in the continental United States, but comparable figures from previous reports of the Forest Service and the Bureau of the Census back to 1870. In its interpretation of the significance of the decline in lumber production it goes far beyond its predecessors because of the growing need for emphasizing the effect of forest exhaustion upon the high prices and the diminishing production of lumber.

In the decennial year 1920 the effort has been made to provide, in Tables 4 and 6, the most complete possible statement of comparable quantitative data for lumber production, by States and species. Table 4 is summarized to show production of the several lumbering regions for 50 years. In the years previous to 1870 lumber production was enumerated only by valuation, and Table 4a exhibits these

[1] A detailed summary of the 1914 lumber production is given in Department of Agriculture Bulletin 506, which contains the figures for 1915.

valuations, thus compiling in one volume the entire lumber production figures of the Government which are regarded as sufficiently reliable and comparable for ordinary reference.

Diagrams have been introduced to illustrate other features of interest, such as the national lumber production during the past century, production by the several lumbering regions for 50 years, numerous curves of production by species, the quantity and mill value of lumber consumed per capita since 1890, the trend of prices of yellow pine and Douglas fir, and the relation of annual growth to consumption.

ACKNOWLEDGMENTS.

The 1920 statistics for the western States were collected through the district offices of the Forest Service at Missoula, Denver, Albuquerque, Ogden, San Francisco, and Portland. The reports for New York were collected by the New York Conservation Commission. The work for the rest of the States east of the Rocky Mountains was done in the Washington office of the Forest Service.

Acknowledgment is made for assistance in the collection and compilation of reports on which this bulletin is based to A. B. Strough, New York State Conservation Commission; and to C. N. Whitney, District 1; Miss F. Ruth Waters, District 2; Quincy Randles, District 3; N. J. Fetherolf, District 4; C. L. Hill, District 5; and C. W. Gould, District 6, of the Forest Service.

The National Lumber Manufacturers' Association, through its affiliated organizations, assisted in securing reports from certain mills. As in previous years, the Bureau of the Census, U. S. Department of Commerce, extended helpful cooperation.

PART I. SIGNIFICANCE OF DECLINING LUMBER PRODUCTION.

In the recent statistics of American lumbering two years are signalized by events of outstanding significance both to the lumber industry and to the public which it serves.

The first was 1907, when the highest point in lumber production was reached, and the production curve started on a long, steep, downward slant, the end of which can not be determined.

The second was 1920. The census of that year has brought out three facts which are not only important but ominous when considered in relation to each other and to the events of preceding years.

1. Production continued to decrease in the face of an accumulated need for the use of lumber which is unparalleled.

2. The average value of lumber at the mills continued to rise to a point far above the high mark set in 1919. There was, in fact, an upheaval of lumber prices such as has never before been experienced, culminating in a peak which dwarfed the previous peaks, and followed by a decline as rapid as the rise. This spectacular event is of more than passing interest, both as an historical fact and as a symptom of economic stress. Yet in fundamental importance it is far surpassed by the third fact, namely, that—

3. Lumber production increased in 11 Western States, but only 1 Eastern State cut more than in 1919. In the other 36 States production decreased. This is fresh evidence of the shift of the main center of lumber production from the southern pine belt to the West. It means not only that the great consuming centers of the East must haul a heavy percentage of their lumber twice as far as before, but also that we are now tapping our last reserve of virgin softwood forest.

This change comes at the end of 300 years of exploitation. It touches the welfare of every individual in our growing population. What does the future hold for us? What steps should be taken to meet national needs? The bare figures suggest questions of this kind but do not answer them. For that reason it is pertinent to discuss with the statistics of 1920 the related conditions in production, prices, and supply.

LUMBER PRODUCTION DECREASED.

The production of lumber in 1920 was 33,800,000,000 feet board measure, which is 2.2 per cent less than the production in the previous year. This, in itself, does not seem a great reduction. The feature of real meaning with regard to production is that 1920 shows one more slip downward, and that we have reached a point where the cut is 27 per cent less than the peak production which occurred in 1907. Figure 1 shows graphically the decline of the last 13 years. While it was not continuous, its trend is unmistakable and its amount notable. The average rate of reduction is 2 per cent per year. The decrease in 1920 was therefore approximately the average for the period since the peak. It was, however, considerably less than the average for the period since 1912, during which the downward slant has been more pronounced.

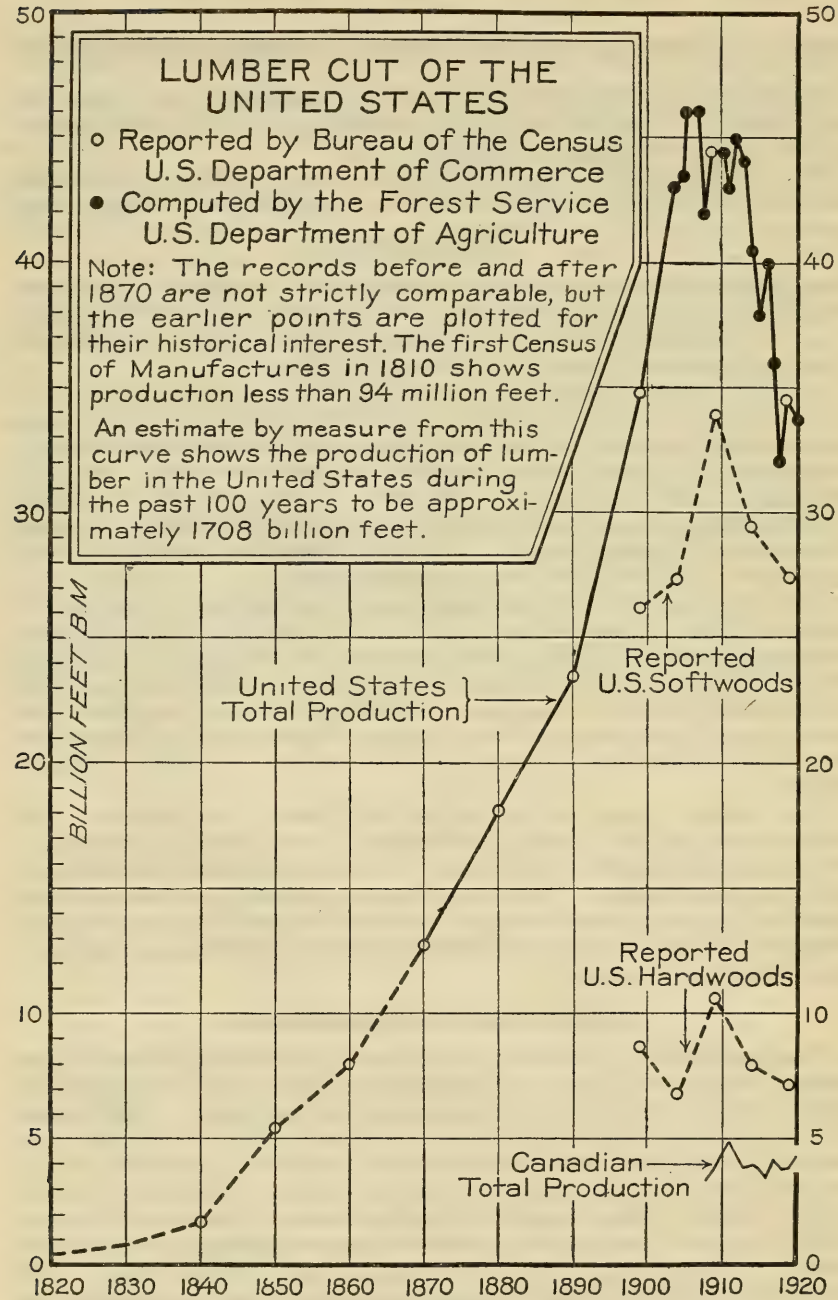

FIG. 1.—The rapid decrease in lumber production is largely due to the fact that four trees are taken from our forests for every one restored. The decrease of production since 1907 is 27 per cent.

This persistent decline in lumber production is the more worthy of attention because the population of the United States has increased by 15 per cent in the last decade. There now exists an amount of unsatisfied demand for construction unequaled at any previous period in our history. Normally, under such conditions, considerable increase would be expected. It is possible, of course, that with the increase of urban residence, under building restrictions, more brick, stone, steel, and concrete are being used for modern types of dwellings. It is also true that the best grades of the most desirable species are no longer so readily obtainable. The substitution of other materials is probably one reason for the decreasing use of wood by an increasing population. But there is at least one other cogent reason, and that is the steadily increasing cost of lumber to the consumer.

Other things being equal, the annual per capita consumption of a commodity affords a measure of its abundance, and a declining per capita consumption indicates an increased economic burden. If supplies are relatively ample, the average person can use the commodity freely. As the supply decreases, rising prices tend to restrict this use.

Figure 2 shows the per capita lumber consumption of the United States continuously for 100 years, contrasted with partial data for other countries. The average consumption in the United States has declined rapidly and constantly from 500 feet or more per person in 1907 to 316 feet in 1920, a decline of 37 per cent in 13 years, or nearly 3 per cent a year. The decline began when the Southern States passed their maximum production, the Central States, the Lake States, and the Northeast having passed their peaks 10 years before. (See Fig. 6.) As soon as national production began to decrease, the steadily increasing population caused the per capita curve to take a downward slant considerably steeper than the one followed in the upward movement previous to the peak. Canada and the United States show the largest per capita consumption in the world because of their great forest possessions in combination with advanced standards of living and means for rapid exploitation of natural resources. The per capita consumption of each is decreasing. The United States now occupies a position very little above that of Newfoundland. Then come Sweden and Russia, followed by Germany and France. Practically the total supply of the latter two comes from man-made forests grown upon areas very much restricted because of the pressing need for the use of all agricultural lands. Next below comes England, which imports practically all of the lumber used, and last of all is Japan, also a heavy importer. If the curve continues to fall at the same rate, the amount of timber used in 1930 by each person in the United States will be below that shown for Russia. It is not a cheerful prospect for Americans who desire to build homes.

A reason why Americans are not buying and using more lumber is indicated in Figure 3, in which "A" illustrates the great increase in the mill value of the lumber consumed by each person subsequent to 1915. The decline from the peak reached in 1906 coincided with the financial panic in 1907. "B" shows the same values reduced to the basis of the purchasing power of money, computed with the figures of 1913 as 100. The average American is using about the same amount of lumber as he did in 1866, fully one-sixth less than in 1890, and 40 per

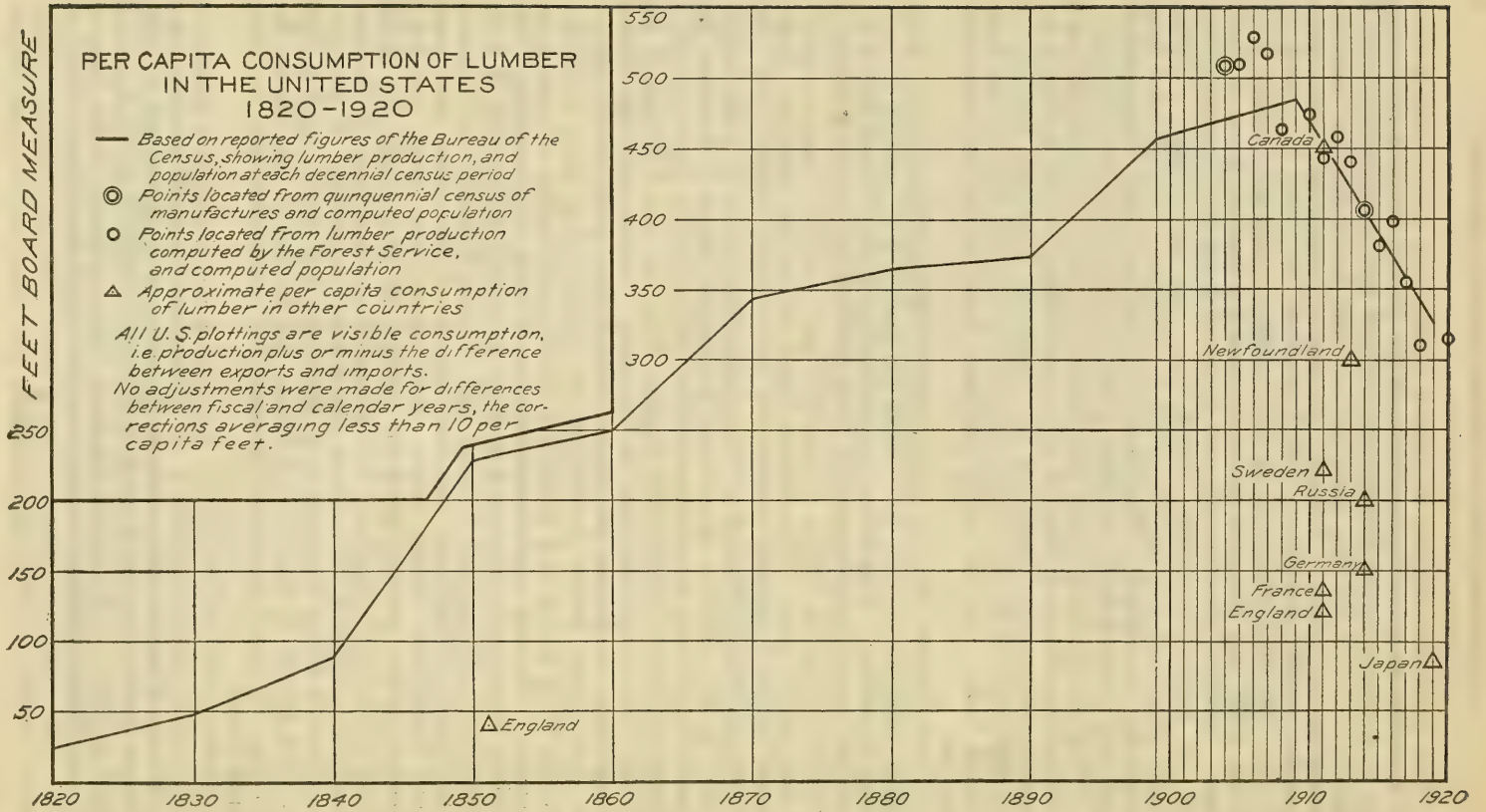

FIG. 2.—If this curve continues to fall at the present rate the average American will use less lumber in 1930 than the average Russian did before the World War.

cent less than in 1896. In 1920 for his reduced yearly quota he paid in dollars three times as much as he did in 1890. Small wonder that he hesitates about building a house, even though average incomes have greatly increased. Even measuring the cost in terms of other commodities, he paid the manufacturer in 1920 more than he did 30 years before for a supply which was nearly one-sixth larger.

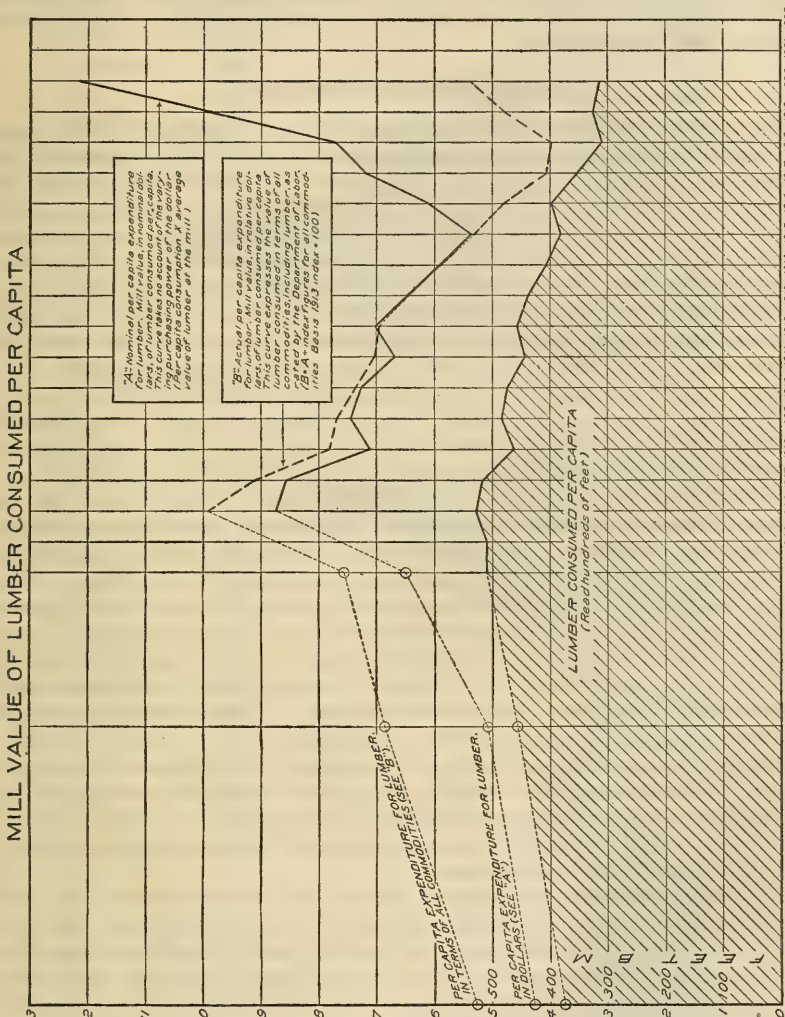

FIG. 3.—This diagram indicates only in part the increasing economic burden upon lumber consumers, because no showing is made of the increases in freight rates or the spread between mill values and retail prices.

Other things being equal, production is in large measure regulated by demand, upon which high prices exert a strong restrictive influence. Extremely high prices may extinguish demand. But the cost of production is the fundamental basis upon which prices rest, and one of the main factors determining cost is the accessibility of the raw material. As the forests shrink and retreat before the mills to more distant, swampy, or mountainous regions, the cost of production or

transportation, or both, inevitably rises, and with it the price of the lumber delivered at the distant market.

In this age of specialization Americans no longer build their homes of hewn logs and whipsawed planks. They are dependent upon the sawmills. If they use lumber, they must pay the prices asked. The incomes of most people are very little in excess of their necessary expenses. Hence even a slight rise in lumber prices results in a widespread tendency to reduce per capita consumption, which operates to decrease the annual cut.

LUMBER PRICES INCREASED.

The average value of lumber at the mill as reported in 1920 was $38.42 per thousand. This is an increase of $8.21 per thousand, or 27 per cent in excess of the value reported in 1919 to the Bureau of the Census. It is the highest average value and the greatest annual increase ever recorded, although the extremely high prices were maintained only a few months. Hand in hand with the persistent decrease in lumber production went a persistent increase in valuation. The value at the mill in 1920 was 247 per cent in excess of the mill value as reported in 1899. In the 21 years since 1899 the value of lumber went up at the rate of fully 5 per cent per average year. On the percentage basis prices rose faster than the cut diminished. (Fig. 4.)

The value reported for 1920 by no means reveals the violent upheaval in prices which occurred in that year, because it is an average for the year, and shows neither the maximum attained nor the subsequent swift decline of lumber prices. Here it will be of interest to review briefly some of the conditions which drove prices to the peak. Following the armistice in 1918 the lumber industry was seriously hampered by conditions created by the war. The logging camps, the mills, and the offices had contributed their quota to the Army, often losing the services of those best qualified to run the job. When the soldiers returned, many of them never regained touch with the work they left. Labor troubles were widespread and serious throughout 1919, and stocks ran low. Throughout the period of demobilization transportation conditions were fairly chaotic, punctuated by embargoes and embarrassed by frequent shortages of cars. Throughout the winter of 1919–20 weather conditions in the lumber woods were particularly unfavorable in the Central States and in the South, the woods being so watersoaked as greatly to hamper lumbering operations.

The Northeast and the Central States had each cut 96 per cent of their original areas of virgin timber. The Lakes States had cut 90 per cent, and the South was not far behind. The South was the only lumbering region east of the Great Plains in which depletion of the timber stands had not gone so far that there was no reasonable chance to increase production. And the South itself was seriously handicapped because of the conditions indicated. Sixty-one per cent of the total remaining saw timber is west of the Great Plains, and the remainder in the East is no longer so distributed as to serve its markets with the former ease.

During the war domestic consumption of lumber was relatively low because most forms of construction, including dwellings and apartment houses, were classed as nonessential activity. Both on the farms and in the cities a vast amount of building was deferred,

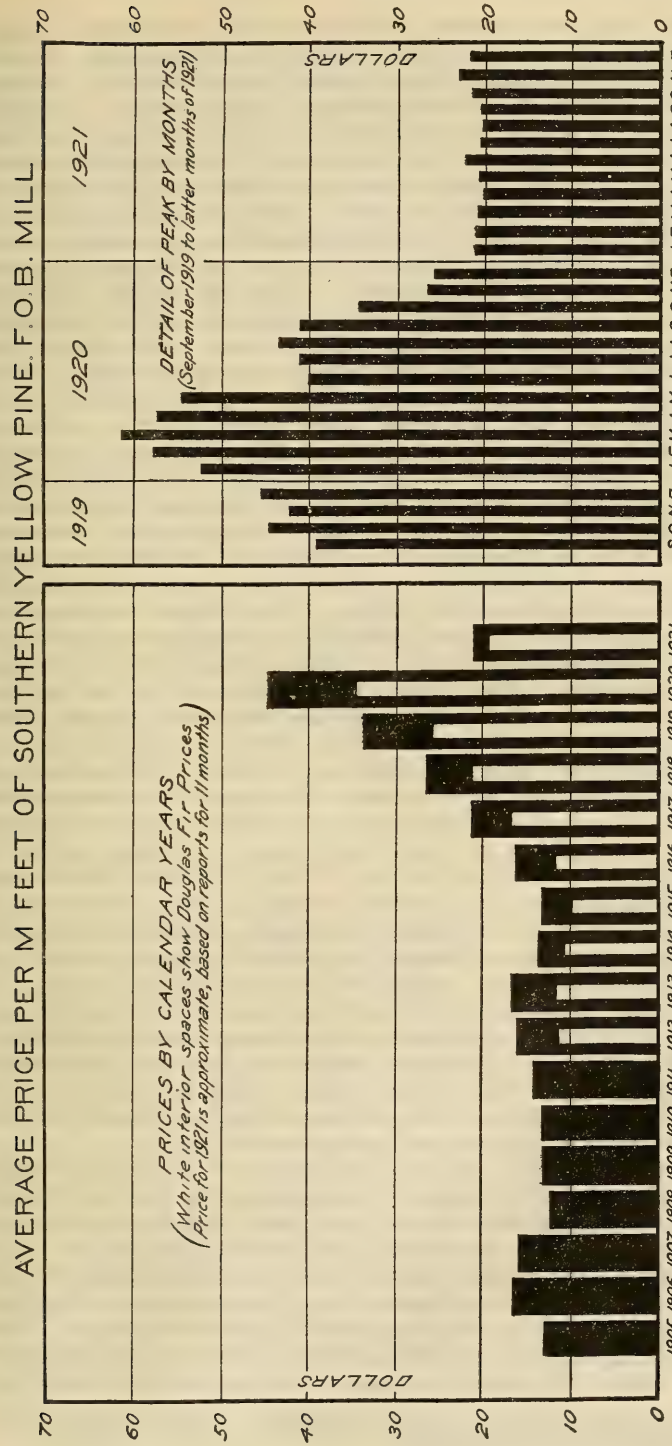

FIG. 4.—The price of lumber, not the quantity remaining on the Pacific coast, is the factor which will determine whether your son will build a house. In 1921, following the peak, prices did not recede to the old low levels. It is difficult to see how still higher prices can be prevented if we continue to destroy the forests without restoring them.

a situation that was revealed in the crowded housing and soaring rents. Before the war a million families lacked houses. In 1918 the construction of houses was less than in 1919, and in 1919 only 70,000 houses were built when 500,000 [2] were needed. A similar postponement of lumber consumption took place in the other large industries using wood as a raw material. Immediately following the armistice this enormous demand was freed of all restriction by the Government and began to exert its influence upon an industry which in the East, at least, was ill prepared to expand its production. For several months following the end of the war there was little activity in the lumber business. Then the wheels of business began to turn, slowly at first but with increasing momentum, under the stimulus of increasing orders. By August, 1919, the demand for lumber was overwhelming, and prices were rising rapidly. Manufacturers were straining to increase their cut, for production was still below normal, and the stocks were badly depleted. The mill price of yellow pine had advanced from $27 a thousand to the unprecedented figure of $40. At this point many people thought the top of the price wave had been reached. Consumers, many of whom assumed that prices would fall at once after the war, were complaining bitterly and urging investigations of alleged price fixing. Domestic orders continued to increase, the price of lumber continued to rise throughout the winter. The demand was such that purchasing agents were virtually bidding against each other for the possession of any kind or grade of lumber, badly milled, half seasoned, or otherwise. The market was practically in the hands of the sellers, who were in a position to ask what they chose. Prices were so unstabilized that no one had an accurate idea of value. In early February, 1920, southern pine went to $55. The eastern mills had no stocks and cars were scarce. By that time home builders were unable to pay the enormous prices asked for lumber, although the building operations of many large firms continued as fast as lumber and workmen could be had. The high rents received may have justified building by wealthy landlords, but there was no chance for the small home builder, especially as bank credits could not be obtained in proportion to the vastly increased cost of construction, which had risen nearly 200 per cent in five years. The conditions were impossible for the maintenance of business on a large scale. In March the demand for lumber checked decidedly. Rumors of price softening became persistent, but just as persistent was the lessening of retail inquiry. The whole mental attitude of Americans had changed, and the period of reckless expenditure was over. The public had made up its mind not to buy.

Then came the crash. On or about March 20 the lumber market went over the top of the greatest price peak ever known, with the southern pine mill price at $61.60, and other woods in proportion. At retail southern pine was costing the public from $66 to $175 a thousand, depending upon the grade and point of consumption; red gum, $247.50; and quartered oak, $385. Concessions to buyers in certain instances were followed by a flood of canceled orders. Prices continued to slip downward, while stocks increased, and numerous mills shut down. By June the market was practically dead, North

[2] In March, 1922, a national conference of builders at Washington, D. C., declared that there is need for the immediate construction of 1,500,000 new houses.

Carolina pine sales being reported at 18 per cent of normal. In December, 9 months after the peak, southern pine had declined to $25.88. Its low postwar level of $20.36 was reached in April, 1921.

Such is the story of the greatest lumber price wave ever recorded. The commonly stated cause was the avalanche of demand which descended upon the lumber industry at a time when especially unfavorable conditions in transportation and manufacture cut off consumers from manufacturers. This statement is true, but it is not the whole truth. A contributing cause was the fact that eastern forests were no longer plentiful and well distributed enough to relation in the chief centers of consumption to make them a sure competitive source of supply, when extraordinary difficulties arose.

The price peak of 1920 was not the first, and it may not be the last. It was a repetition on a larger scale of previous history. Following the Civil War there was a price peak, definitely marked, but not nearly as high. At that time bidding for existing lumber was not so intense, because business was not transacted as rapidly, and ample forests within reasonable reach of the consuming centers made it obvious that there was plenty for all immediate needs. Yet at that time the accumulated demand, increasing consumption, inflation of currency, and lengthening lines of transportation to points in the Lake States, caused lumber prices to settle at a new high level, with softwoods about 33 per cent and hardwoods 100 per cent higher than the averages before the Civil War. So, following the recession of the price wave in 1920 a similar new higher level may be in process of establishment. (See Fig. 4.) From January, 1921, to March, 1922. southern pine varied but little from the average mill price of $21.18. At this stage it is about 50 per cent higher than the average from 1905 to 1916, but whether this is a permanent new level it is still too early to determine. A much smaller advance in prices would be ample to cut down the per capita consumption of lumber.

CENTER OF PRODUCTION SHIFTING TO THE PACIFIC COAST.

For 100 years the lumber industry has been in the process of migration from one forested region to another. The first lumbering took place along the Atlantic Coast, from Maine southward to the Royal Colonies in Virginia and the Carolinas. But lumbering as we now know it did not get under full headway until nearly the middle of the last century, with the introduction of improved forms of machinery and large merchant mills. As the first cut of pine in the more thickly settled coast regions drew near its end the exploitation of the white pine forests of the Lake States began and the hardwood regions of the central Appalachians were opened to the market. As the cut of the Lake States drew to its close many lumber manufacturers of that region removed their operations to the South and began the attack upon the great belt of long-leaf pine stretching from Virginia to Texas. Each of these moves increased the distance between the centers of production and the centers of consumption. Now four-fifths of the original southern pine is gone, and there is in progress a marked drift of lumbermen from the Southern States to the Pacific Coast, and to the northern part of the Rocky Mountains, known as the Inland Empire.[3]

[3] In this general statement it is not intended to overlook the fact that some important lumber manufacturing firms moved from New York directly to the South, and others from the Lake States to the West.

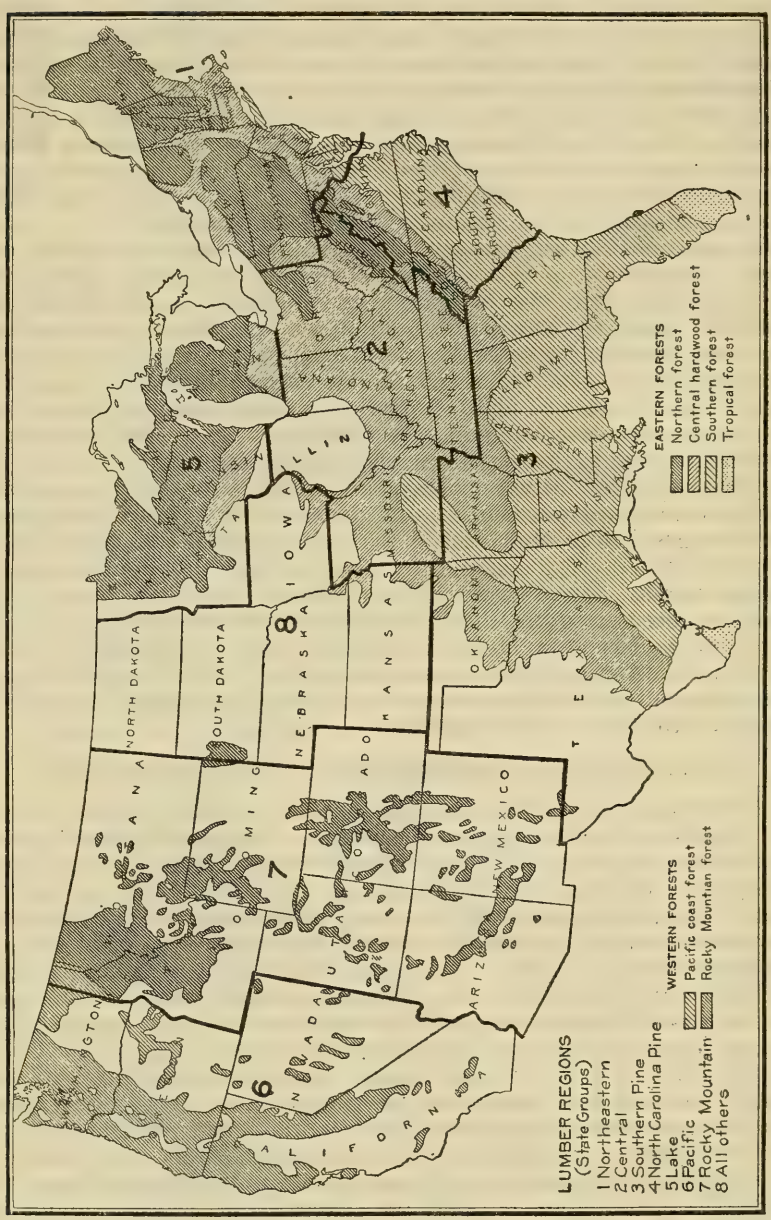

FIG. 5.—Half of our remaining saw timber lies in that relatively small forest area along the Pacific coast, 2,000 to 3,000 miles distant from the greatest centers of consumption. The freight rate from the coast is more than the wholesale price of first-grade hardwoods in Civil War times.

For several years lumbering operations on the Pacific Coast have been increasing.

In 1920, with the exception of New York, the only States which increased their production were those of the Pacific group and part of those in the Rocky Mountains. The growing ascendancy of the West is plainly evident, as shown by Figure 6. The production curves of the Southern States are falling rapidly, but those of the Rocky Mountains and the Pacific coast are ascending upon a steeper slant, and for the first time they exceed the production of the southern pine group. Whether there will be a period of increased cut of southern timber before the southern graph descends still further is a question upon which no confident prediction can be made.

As a further indication of the regional shift the number of Class 5 [4] mills on the Pacific coast increased by 18 per cent in 1920, while the South and the Lake States each apparently lost about one-eighth of their Class 5 mills. There is a degree of uncertainty in this evidence because 1920 was a year of such reduced production in the East that some of the southern mills included in this count may merely have fallen into a lower production class. On the other hand, some of the western mills of Class 4 may have increased their cut to Class 5 dimensions. There is less doubt, however, when we examine the mill figures on another basis, including Class 3, 4, and 5 mills in the comparison, which means all mills cutting over a million feet per annum. Of such mills the Pacific coast showed a gain of 169, or 26.7 per cent, in 1920 as compared with 1919, while the number of similar mills in the southern pine and North Carolina pine groups of States, combined, decreased by 490, or 19.7 per cent. In general it appears that many southern mills are nearing the end of their cut and either going out of business or moving to the West.

The recapitulation under Table 4 shows that all of the lumbering regions except the Pacific and Rocky Mountains are past their maximum production. Although the South probably will retain a strong position in the lumber production of the country for a number of years, there is every indication that its ascendency in the lumber world has passed the zenith and that henceforth we must look more and more to the West as the main center of supply.

Figures 7, 8, 9, and 10 show that in 1920 most of the species exhibiting an increased cut are western species. During 1919 and 1920 western lumber greatly extended its hold upon the eastern market. The greatly reduced cut of the Lake States and the inability of the storm-bound South to deliver diminished the competing power of those regions. The greatly increased prices for the first time enabled the timber of the Pacific slope to compete on even terms with the product of the eastern forests. Within a year or 18 months Douglas fir became the principal species throughout the greater part of the Middle West. It captured Minneapolis, a stronghold of white pine. It was found in Chicago in greater volume than any other species. In Kansas City it formed more than 50 per cent of the lumber stocks. In spite of strikes, storms, and embargoes, the western invasion plowed east to the very citadels of eastern production.

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[4] Class 5 mills are those of the largest size, cutting 10,000,000 feet or more annually. For explanation of mill classes see headings of Table 3.

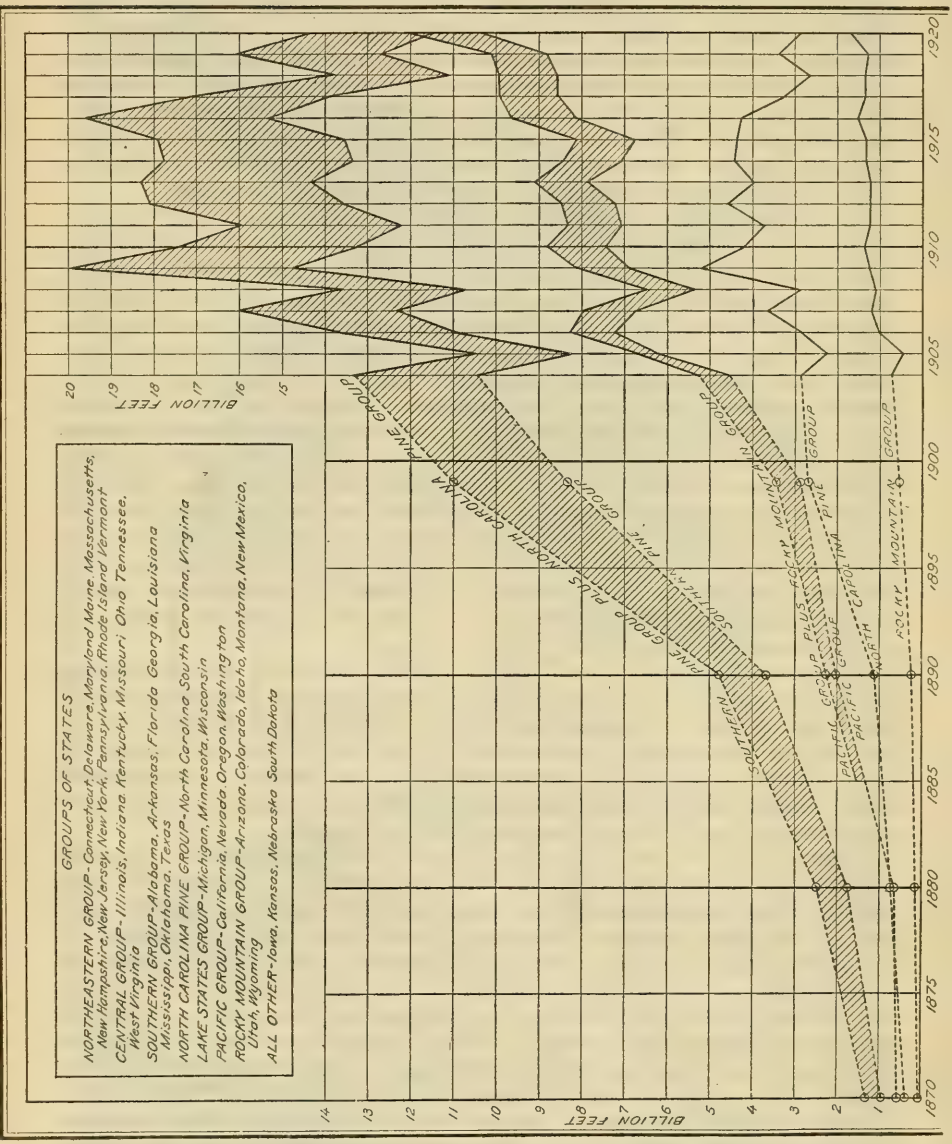
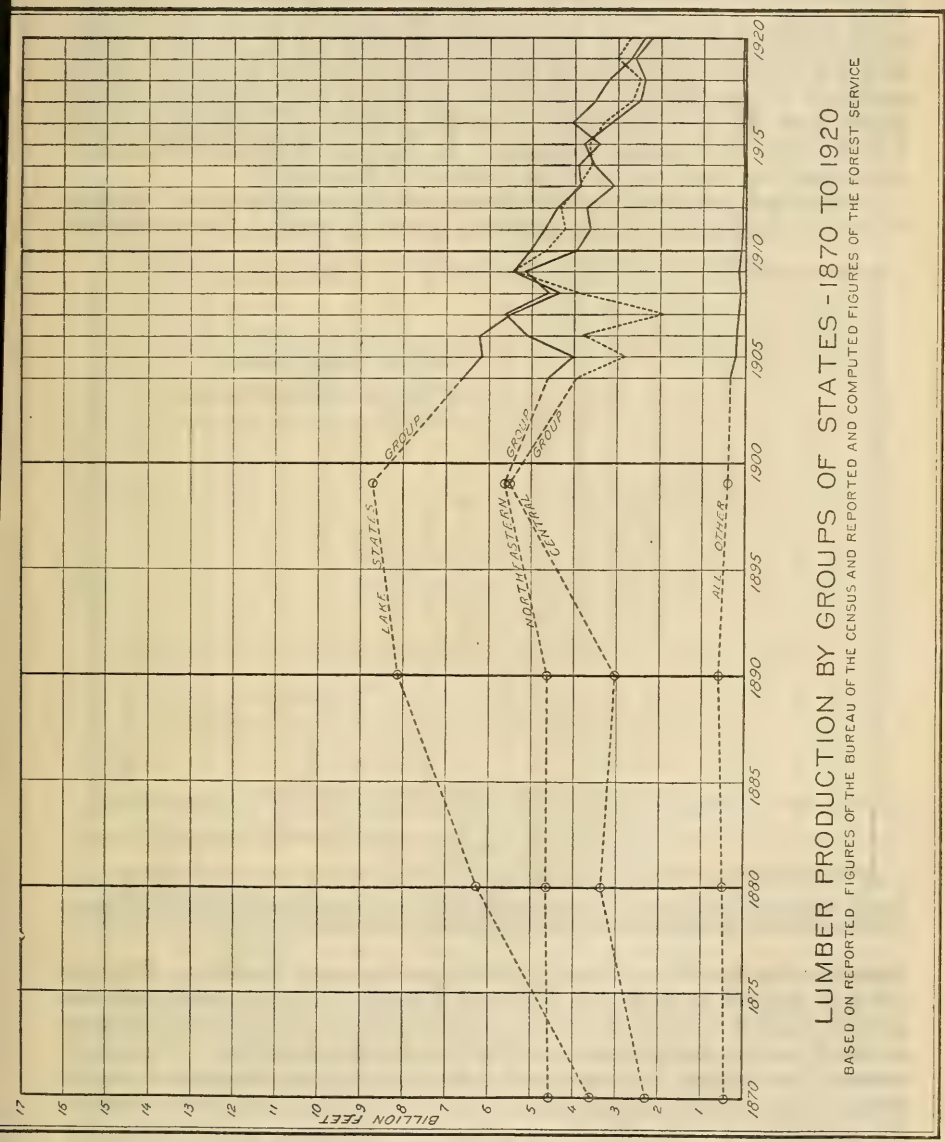


FIG. 6.—In 1920, for the first time, the graph of western lumber production overlapped that of the South. The produc-
long before the Pacific timber



on of all the eastern regions is declining. An adequate source of lumber supply for the East should be created
ows signs of exhaustion.

No previous shift of location has been marked by such changes in lumbering conditions as are seen in the move from the South to the West. In the South and the Lake States there was relatively little obstruction to lumbering due to mountainous topography. In the West much of the national forest timber, and some of the private timber also, is at present inaccessible on account of the mountains and will require heavy expenditures to get it out. Already about one-sixth of the western timber has been cut, and naturally it was taken from the best and most accessible stands. As time goes on it will become increasingly expensive to log the more remote areas. Less yearlong work can be done because of deep snow.

In the East practically all the timber was privately owned. In the West only 53 per cent of the timber is privately owned, the remainder

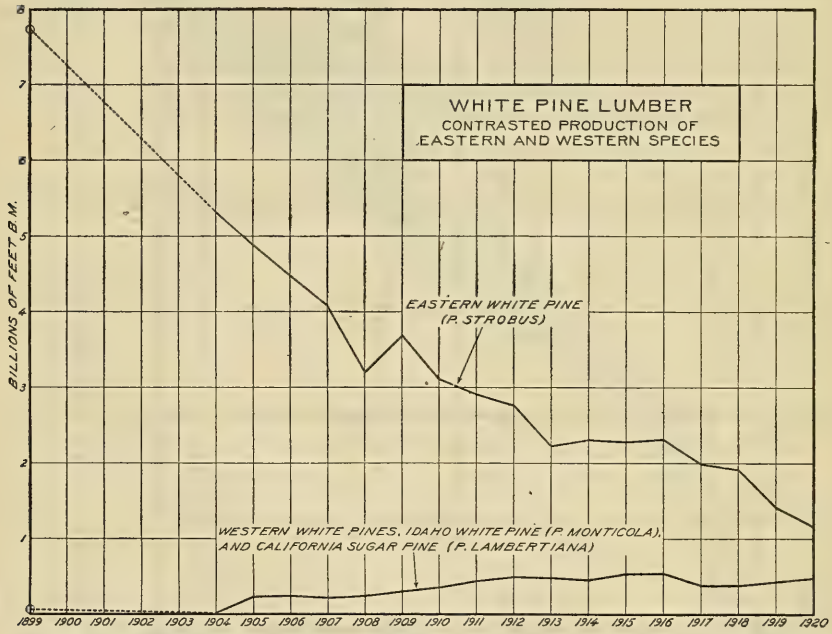


FIG. 7.—Millions of acres which would grow eastern white pine are awaiting reforestation. European nations would not think of neglecting such an opportunity to set their lands and their people at work.

belonging to the Government, the States, or municipalities. Thirty-six per cent of it is within National Forests. The ownership of the private timber is concentrated to a marked degree. Never before was so much timber controlled by so few firms and individuals. Although some of the largest holdings have been decreased within recent years, many of the small holdings have been consolidated into units suitable for operation. This situation apparently offers an opportunity for centralized management, in marketing as well as production, such as has not existed before. On the other hand, the heavy timber holdings of the Government within the national forests provide a means which did not exist in the eastern regions for leveling inequalities in production and prices and maintaining competitive conditions.

The most significant change resulting from the shift is the increased distance between the main center of production and the consuming

centers of the country. Not quite 50 per cent of the lumber produced in the United States is consumed in the States north of Tennessee and east of Iowa. Heretofore the average haul of timber to this region has been between 500 and 1,000 miles. Hereafter a large amount of the supply will have to be hauled between 2,000 and 3,000 miles, although a considerable portion of the western timber may come by sea through the Panama Canal to the East coast markets. In the years when much more timber was accessible to water-borne traffic, transportation cost from $1 to $3 per thousand feet. In the year of this report it costs about $9 per thousand from the South and about $20 [5] from the Pacific coast to New York.

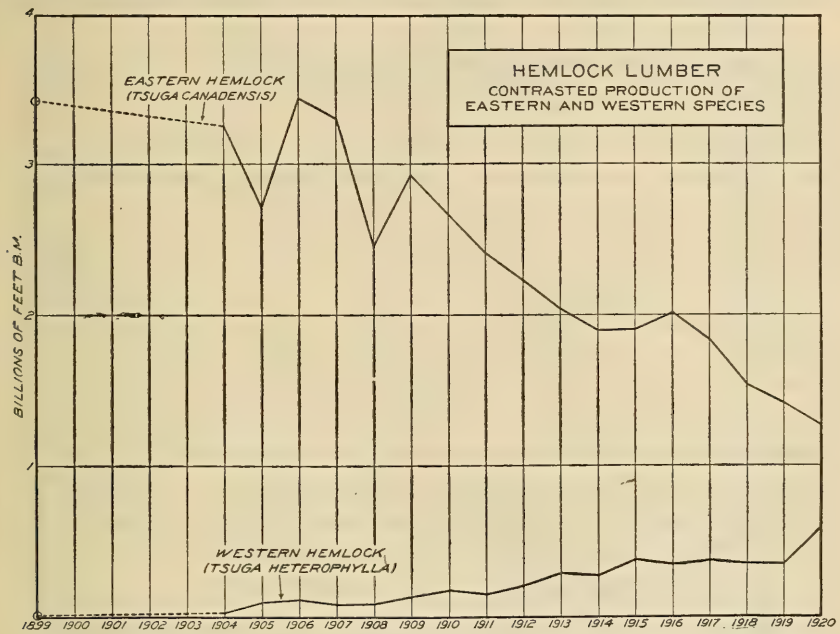


FIG. 8.—The curves for hemlock and white pine illustrate the shrinkage of eastern lumbering as compared with increases in the West.

Not a single factor in the new situation tends to reduce the cost of lumber. On the contrary, almost all factors tend to increase the cost. It is difficult to see, under such circumstances, how any substantial reduction of prices may be expected. The additional cost of transportation across the continent is as much as our fathers paid for first-grade hardwoods before the Civil War.

Price is the factor which will determine hereafter whether the average American will use less lumber or more. There is plenty of timber on the west coast for immediate needs, but if the price is so high that the per capita curve continues steeply downward, then the long-prophesied shortage is already at the door.

The long step to the Pacific coast is the final shift in the migration of the lumber industry, unless Americans should desire to cross the

[5] In March, 1922, the steamer rate per thousand from the West coast to New York was approximately $18.25.

Pacific in the search for new sources of lumber. The coast has the last large supply of North America, and the chances for securing softwoods elsewhere are not favorable, although the suggestion has repeatedly been made that once the native forests are exhausted we have only to purchase our lumber from other countries.

We must have huge quantities of softwood timber, the best of all woods for general purposes. The remaining pine, fir, spruce, and larch of the world are gathered in three great bodies. One is in northwestern America and Canada, another in Scandinavia and Finland, and the third in European and Asiatic Russia. There is little hope from Canada, for her so-called limitless forests are rapidly being developed to their capacity for the needs within the British Empire. The

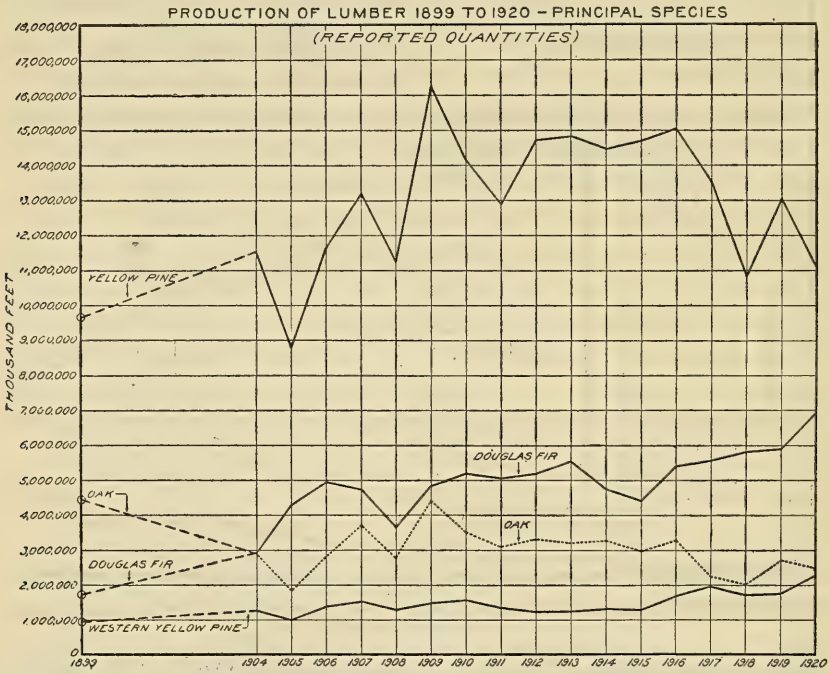


FIG. 9.—Yellow pine and Douglas fir are now rivals for first place in point of production. It is possible that within the next few years the graphs of these two species will cross.

Alaskan forests are better adapted to pulpwood than to lumber. The largest part of the European forest (except that in Russia) is man-made, and by no stretch of the imagination can one fancy that its surplus will ever supply even a fraction of our huge consumption in addition to the needs of its owners. Sooner or later Russia will resume her industrial activity and rebuild her thousands of dilapidated villages. A great part of her European timber will then be needed at home. For any surplus from European forests we should have to compete with the rest of the world, and the mere fact of our competition would inevitably increase the price.

The forests of Siberia are ringed about by the nations of Europe and Asia, some of which already have an eager eye upon this timber because it is essential to their participation in world trade. All of

these nations are in greater actual need for timber than the United States.

It is practically certain that China, with her hundreds of millions, will develop industrially. Although for the present she imports from America, when ours is gone she will probably requisition great quantities of the Siberian timber.

Add to this the import demands of Japan and England, and the lesser requirements of Australia. Nearly 40 per cent of all human beings live within 2,500 miles of this timber, and even England, the most distant nation of those mentioned, is nearer to it than is Chicago. It requires little imagination to see that by the time our needs drive

FIG. 10.—Of these important softwoods two are rapidly declining and the others show no marked increase. With southern pine also decreasing heavy requirements must be made upon Douglas fir and western yellow pine.

us to seek heavy importations, the supplies from that source will be largely monopolized by other countries. Even if all the Siberian timber were at the undisputed call of the United States, the quantity available for annual export would amount to only one-fourth or one-fifth of our demand for lumber. It is not to be assumed that even our present financial supremacy will enable us to shoulder out of the market nations which have that timber near at hand and then transport it three or four times as far to supply our needs. If the cost of transportation from the Pacific coast is a serious economic burden, what shall be said of transportation from Siberia? Obviously, it would be very unwise to depend upon imports for any great part of our future lumber supply.

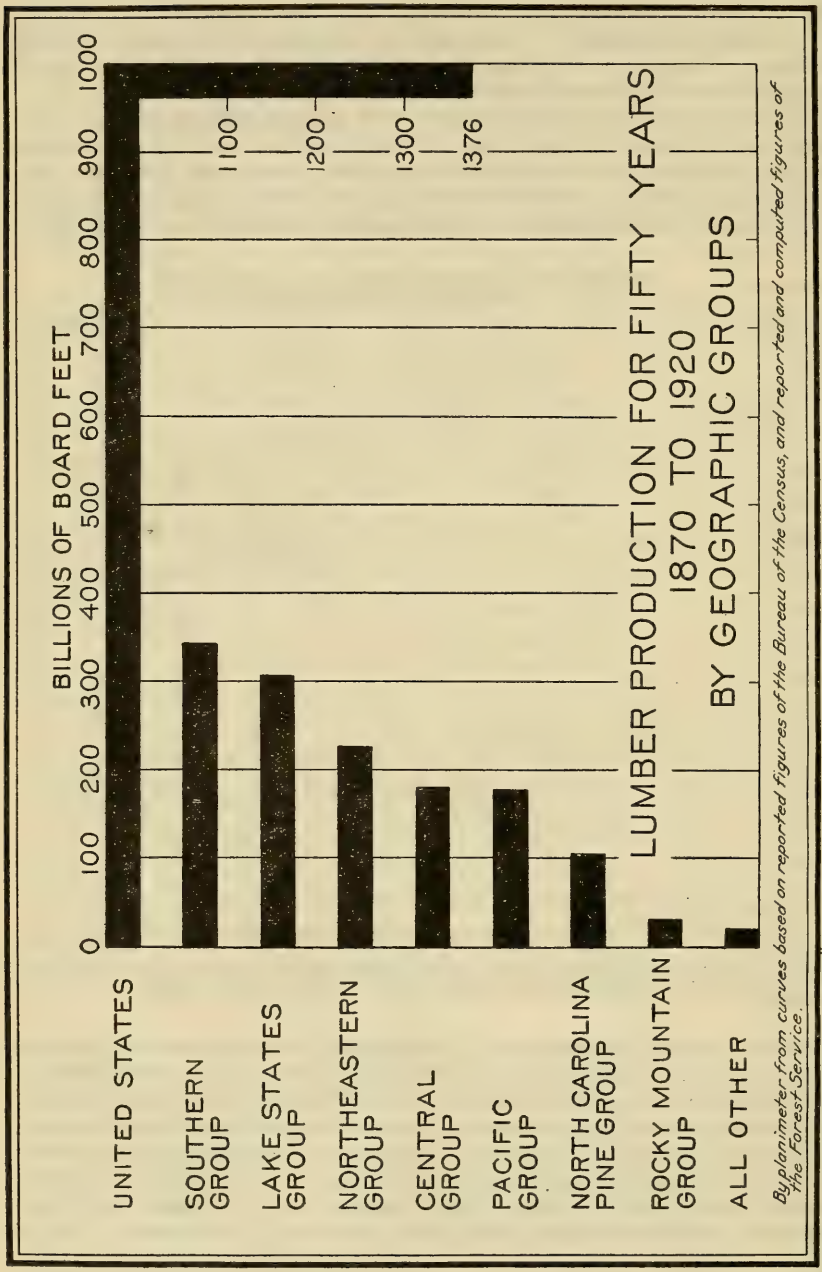


FIG. 11.—The industrial development of the United States required five times as much lumber in the last half century as in the 50 years preceding 1870. Shall that development now be cramped for lack of forest products when we have 81,000,000 acres of cut-over lands awaiting reforestation?

Measures of economy, though helpful, will be found insufficient where such an enormous demand is involved. We must utilize them to the utmost, but economize as we will, the introduction of inferior species, the use of lumber substitutes, the general application of timber preservatives, all of them together can not account for more than a fraction of the 35,000,000,000 feet of lumber a year which we must have unless our present standards of living and industrial facilities are to be greatly reduced.

TIMBER GROWING THE ONLY REMEDY.

It is already too late to avoid the results of the past century of exploitation. The pinch for lumber will be upon us before new forests can be grown. It will be felt not only in the scarcity or increased cost of wooden articles. Directly or indirectly every commodity of life will cost more because of the depleted supply of forest products. Every American will pay an unnecessarily large part of his income for shelter and food and clothing, fuel, transportation and amusements, necessities and luxuries alike, because wood will be no longer plentiful and near at hand. This economic punishment will increase in severity as time goes on. There is only one way by which its pressure can be relieved and removed, and that is by growing enough timber for the national needs.

There seems to be among the American people a sort of naive confidence that each form of national resource will last indefinitely, no matter how great the inroads upon it. There was mild surprise when the buffalo vanished. The practical exhaustion of free Government farm lands aroused a half resentful disappointment. The peak of lumber prices caused widespread indignation, and was attributed to every sort of cause except the fundamental reason that depletion had so localized the remaining timber supplies as to make them unavailable. The fact that we are beginning in earnest to cut our last reserve of virgin timber, with no suitable cycles of young forest to take its place, may not cause a ripple of public sentiment, for the public has heard a great deal of these things and as yet no cataclysm has occurred. There will be no cataclysm—no sudden deprivation of all timber products. There will always be lumber in our markets, but if the price is beyond the reach of the average American, it might as well not be there, as far as he is concerned. More idle lands, more idle men, less home ownership, and the slow throttling of demand for lumber by the rising tide of prices will be the evidence of our failure to restore the forests.

Timber is essential to national life of the standard which Americans demand. In peace or war it is a form of wealth the possession of which is partial assurance of success; the lack of which will be found a heavy handicap. Therefore as a measure of self-preservation such steps must be taken as will assure the national supply.

Forest culture in the United States is inevitable. Price pressure will attend to that. Once our house is put in order, timber will no longer be the volunteer product of the public domain, but a crop, planted, tended, and cut as regularly as those of the farms. It may never again be as plentiful or as cheap as in the past, but after awhile there will be enough, and perhaps some to spare for less fortunate

countries. Thus, muddling through in Anglo-Saxon fashion, we shall finally bridge the gap between the pioneer methods of the past and scientific use of forest lands.

It is by no means a cheerless future that lies before us. On the contrary, it is full of promise—after the pinch is past. It means restoration instead of destruction. It means permanence of the lumber industry instead of sawmills wandering from end to end of the country. It means the steady flow of national wealth from the

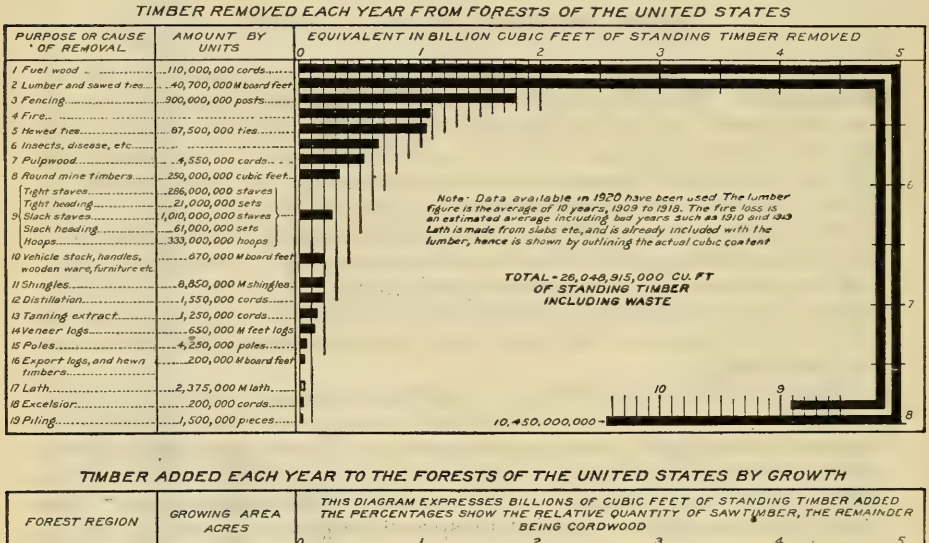


FIG. 12.—Only 35 per cent of the wood now growing is fit for lumber. The volunteer crop of untended and fire-swept forests naturally can not equal the product of intelligent management.

great areas now treeless which once nourished the magnificent forests of the past. It guarantees work as essential and constructive as that of the farmer, with steady wages for hundreds of thousands of men. For many it will prove an opening door of opportunity to get away from the cities and back to the land. The secondary industries which would spring up would provide work, wages, and prosperity for additional hundreds of thousands of skilled artisans. A dozen Governments of Europe would eagerly embrace such an opportunity to provide happy and healthful occupations for the unemployed, and utilize waste lands so fortunately located with respect to climatic conditions that they are capable of growing the most valuable forest

products of the world. The need is plain. With every passing year it becomes more urgent, for timber is the slowest of all crops to mature, and the mills are cutting four trees for every one restored.

The task is great. Yet the obstacles are not insurmountable. On the other hand, there is not much latitude of choice, for America must have timber, and the only way to get the amount needed is to grow it. Our timber supply and our wheat supply stand in the same category. There is no doubt that whatever may be necessary to insure the continued growing of wheat will be done. The restoration of American forests awaits only the impulse of a clean-cut public conviction that timber is essential and that a new crop must be grown.

PART II. STATISTICS OF PRODUCTION AND VALUE.

TOTAL LUMBER PRODUCTION.

The quantity of lumber reported cut in 1920 by 15,978 mills was 29,878,360,000 board feet. The output of 2,668 mills cutting less than 50,000 board feet each is not included in the reported cut. In addition, 2,483 mills were reported idle.

The estimated total lumber production was 33,800,000,000 feet board measure. This is a decrease in production of 2.2 per cent from the 1919 figures of the Bureau of the Census and 27 per cent less than the estimated peak of production in 1907. The computed number of mills operating (23,242) is less than half the number canvassed by the Bureau of the Census in 1909.

The reported lumber cut, the number of active mills reporting, and the estimated annual total cut are given in Table 1 for each year since 1899 for which data have been compiled. The statistics are not directly comparable for all of the years, since the intensiveness of the canvass made in different years must be taken into consideration. In the enumerations for 1899, 1909, and 1919 field agents of the Bureau of the Census were employed which permitted the tabulation of the output of practically all mills from direct reports.

TABLE 1.—*Quantity of lumber reported, number of active sawmills reporting, and estimated total cut, 1899 and 1904–1920.*

Year.	Reported cut of lumber.	Active mills reporting.	Estimated total cut of lumber.
	M feet b. m.		*M feet b. m.*
1899	35,084,166	31,833	35,084,166
1904 [1]	34,135,139	[2] 18,277	43,000,000
1905	30,502,961	11,666	43,500,000
1906	37,550,736	22,398	46,000,000
1907 [3]	40,256,154	28,850	46,000,000
1908 [3]	33,224,369	31,231	42,000,000
1909	44,509,761	[4] 46,584	44,509,761
1910 [3]	40,018,282	[2] 31,934	44,500,000
1911 [3]	37,003,207	[2] 28,107	43,000,000
1912	39,158,414	[2] 29,005	45,000,000
1913	38,387,009	[2] 21,668	44,000,000
1914 [1]	37,346,023	[2] 27,506	40,500,000
1915	31,241,734	[2] 16,815	38,000,000
1916	34,791,385	[2] 17,269	40,000,000
1917	33,192,911	[2] 16,420	36,000,000
1918	29,362,020	[2] 14.753	32,000,000
1919	34,552,076	[5] 29,534	34,552,076
1920	29,878,360	[2] 15,978	33,800,000

[1] Custom mills excluded.
[2] Mills cutting under 50 M feet excluded.
[3] Including mills which manufacture lath and shingles exclusively (1,500 estimated).
[4] Includes 4,543 mills cutting less than 50 M feet, and all cooperage, veneer, millwork, box, furniture, and other factories cutting any lumber at all in 1909.
[5] Includes custom mills and 2,655 mills cutting under 50 M each.

LUMBER PRODUCTION BY CLASSES OF MILLS.

As in previous years, the mills were arbitrarily divided into classes according to the quantity reported cut. These classes are shown in Table 2, with the computed [6] number of mills operating and the

[6] "Computed," as used in this bulletin, expresses results obtained by the extension of figures based on actual returns, so as to show totals for approximately all sawmills, whether or not reports were received from them.

computed total production of each of the last six years, 1915 to 1920, inclusive.

The striking difference in size between Class 5 and Class 1 mills as illustrated in Plate I and Plate II, respectively, helps to explain why it is that more than two-thirds of the aggregate output of American sawmills was produced by 1,302 mills, or only 5.6 per cent of the 23,242 computed to have been in operation. The percentage of the cut produced by the class of mills cutting 10,000,000 feet and over annually (class 5) has increased materially during the last 12 years. In 1909 this class of mills produced 43.09 per cent of the total cut for the year, while in 1920 the same class of mills cut 57.59 per cent of the total. But in general, for the last six years the proportional production by the five mill classes has changed but little.

TABLE 2.—*Reported production of lumber, 1919, and computed totals 1915 to 1918, and 1920, by classes of mills.*

Classes.	Mills.		Computed quantity cut.	
	Computed number operating.	Per cent.	M feet b. m.	Per cent.
All classes:				
1915	29,951	100.00	37,011,656	100.00
1916	30,081	100.00	39,807,251	100.00
1917	24,815	100.00	35,831,239	100.00
1918	22,546	100.00	31,890,494	100.00
1919[1]	29,534	100.00	34,552,076	100.00
1920	23,242	100.00	33,798,800	100.00
Class 5; 10,000 M feet and over per year:				
1915	846	2.82	20,669,746	55.84
1916	925	3.08	23,310,137	58.56
1917	899	3.62	22,148,570	61.81
1918	785	3.48	18,970,552	59.49
1919[1]	792	2.68	18,814,099	54.45
1920	795	3.42	19,466,600	57.59
Class 4; 5,000 M feet to 9,999 M feet per year:				
1915	453	1.51	3,224,448	8.71
1916	484	1.61	3,513,767	8.82
1917	459	1.85	3,360,502	9.38
1918	505	2.24	3,567,104	11.19
1919[1]	503	1.70	3,544,609	10.26
1920	507	2.18	3,589,600	10.62
Class 3; 1,000 M to 4,999 M feet per year:				
1915	3,191	10.66	6,201,864	16.76
1916	3,041	10.11	5,858,675	14.72
1917	2,352	9.48	4,615,941	12.88
1918	2,194	9.73	4,270,755	13.39
1919[1]	3,211	10.87	5,972,196	17.28
1920	2,730	11.75	5,305,900	15.70
Class 2; 500 M to 999 M feet per year:				
1915	4,198	14.02	2,941,264	7.95
1916	4,594	15.27	3,096,760	7.78
1917	3,689	14.87	2,460,685	6.87
1918	3,183	14.12	2,138,005	6.70
1919[1]	3,977	13.47	2,662,855	7.71
1920	3,503	15.07	2,341,200	6.93
Class 1; 50 M to 499 M feet per year:				
1915	21,263	70.99	3,974,334	10.74
1916	21,037	69.93	4,027,912	10.12
1917	17,416	70,18	3,245,541	9.06
1918	15,879	70.43	2,944,078	9.23
1919[1]	18,396	62.29	3,473,750	10.05
1920	15,707	67.58	3,095,500	9.16

[1] The data shown for 1919 is quantity actually reported cut, and the total for all classes includes 2,655 mills or 8.99 per cent cutting under 50 M feet, each reporting a total quantity of 84,567 M feet of 0.25 per cent.

Table 3 shows the reported cut in each State arranged by mill classes. The 764 Class 5 mills reporting accounted for 63 per cent of the total reported cut. Of the Class 5 mills 286 are located in the Pacific group of States. This is an increase of 44 mills, or 18 per cent since the enumeration by the census in 1919.

The Lake States show a reduction of 11 Class 5 mills, or 12 per cent since 1919, although the number in Wisconsin increased. The principal reduction was in Michigan. Some mills formerly rated in Class 5, now appear in Class 4 through reduction of their output.

The indication in the South are that one-eighth or more of the Class 5 mills either cut out in 1920 or reduced their cut to the Class 4 limits. The situation in the South was so unfavorable in 1920 that fully dependable deductions can not be made. The reports for 1921 should reveal to what extent the productive capacity of the South has been reduced.

TABLE 3.—*Sawmills classified according to reported quantity of lumber cut, by States, 1920.*

State.	Aggregate.		Class 5 (mills cutting over 10,000 M feet).		Class 4 (mills cutting from 5,000 M to 9,999 M feet).		Class 3 (mills cutting from 1,000 M to 4,999 M feet).		Class 2 (mills cutting from 500 M to 999 M feet).		Class 1 (mills cutting from 50 M to 499 M feet).	
	Number of active mills reporting.	Quantity M feet b. m.	Number.	Quantity M feet b. m.	Number.	Quantity M feet b. m.	Number.	Quantity M feet b. m.	Number.	Quantity M feet b. m.	Number.	Quantity M feet b. m.
United States	15,978	29,878,360	764	18,764,968	466	3,295,672	2,114	4,222,552	2,381	1,595,346	10,253	1,999,822
Alabama	903	1,108,188	22	428,102	26	173,715	173	304,331	157	104,693	525	97,347
Arizona	20	120,495	5	114,940			1		1		13	[1] 5,555
Arkansas	656	1,148,158	32	623,690	25	190,390	102	194,744	106	70,099	391	69,235
California and Nevada	195	1,482,102	40	[2] 1,263,053	9	61,725	53	123,870	28	18,914	65	[2] 14,540
Colorado	151	67,847			1		19	[3] 37,392	18	11,726	113	18,729
Connecticut	122	44,996					6	8,225	26	19,354	90	17,417
Delaware	34	11,990					4	5,160	3	1,500	27	5,330
Florida	204	863,013	28	562,048	17	123,451	67	144,042	28	19,521	64	13,951
Georgia	713	599,739	8	145,564	20	130,755	97	153,893	140	91,816	448	77,711
Idaho	188	969,576	23	840,441	6	43,969	23	48,489	28	18,579	108	18,098
Illinois	129	44,469			1		7	[3] 18,372	12	7,729	109	18,368
Indiana	404	210,045			2		54	[4] 117,785	50	33,753	298	58,507
Iowa	53	12,617					2		3	[5] 5,835	48	6,782
Kansas and Nebraska	5	4,245					2				3	[5 6] 4,245
Kentucky	558	270,882	3	42,311	7	50,793	25	54,260	61	39,467	462	84,051
Louisiana	271	2,719,761	85	2,242,500	42	304,162	55	140,812	28	18,848	61	13,439
Maine	441	450,196	4	69,032	13	84,676	113	194,465	76	51,749	235	50,274
Maryland	221	65,202			1		9	[3] 16,295	25	17,128	186	31,779
Massachusetts	191	100,266			1		32	[3] 52,007	34	22,107	124	26,152
Michigan	243	726,147	19	296,268	41	303,274	34	88,297	22	14,483	127	23,825
Minnesota	246	556,265	14	409,860	10	67,466	15	34,915	14	9,125	193	34,899
Mississippi	648	1,677,469	48	1,075,267	31	218,547	116	240,151	111	74,121	342	69,383
Missouri	405	231,361	3	38,273	5	40,715	36	66,594	42	30,515	319	55,264
Montana	124	409,667	8	309,225	1		31	[3] 81,427	8	6,426	76	12,589
New Hampshire	223	223,376	1		2		84	[7] 171,101	46	32,618	90	19,657

[1] Includes the cut of 1 mill in class 3 and 1 mill in class 2.
[2] Includes the cut of 1 mill in Nevada.
[3] Includes the cut of 1 mill in class 4.
[4] Includes the cut of 2 mills in class 4.
[5] Includes the cut of 2 mills in class 3.
[6] Includes the cut of 2 mills in Nebraska.
[7] Includes the cut of 1 mill in class 5 and 2 mills in class 4.

TABLE 3.—*Sawmills classified according to reported quantity of lumber cut, by States, 1920*—Continued.

State.	Aggregate.		Class 5 (mills cutting over 10,000 M feet).		Class 4 (mills cutting from 5,000 M to 9,999 M feet).		Class 3 (mills cutting from 1,000 M to 4,999 M feet).		Class 2 (mills cutting from 500 M to 999 M feet).		Class 1 (mills cutting from 50 M to 499 M feet).	
	Number of active mills reporting.	Quantity M feet b. m.	Number.	Quantity M feet b. m.	Number.	Quantity M feet b. m.	Number.	Quantity M feet b. m.	Number.	Quantity M feet b. m.	Number.	Quantity M feet b. m.
New Jersey	74	16,466							8	5,427	66	11,039
New Mexico	60	109,882	5	77190	2		5	[4] 21,929	5	3,571	43	7,192
New York	1,206	410,909	3	37,669	4	33,101	38	70,448	144	95,381	1,017	174,310
North Carolina	1,215	786,412	10	123,237	17	122,520	136	253,211	197	126,819	855	160,625
Ohio	473	185,881	1				25	[8] 57,750	78	53,123	369	75,008
Oklahoma	78	154,598	5	118,581			11	20,340	9	5,779	53	9,898
Oregon	659	3,316,098	82	2,531,117	37	249,434	185	413,817	103	69,050	252	52,680
Pennsylvania	832	401,660	6	121,253	5	43,542	22	34,568	98	67,147	701	135,150
Rhode Island	19	7,489					1		6	[9] 4,584	12	2,905
South Carolina	368	520,210	16	272,787	12	79,630	48	91,995	57	38,474	235	37,324
South Dakota	44	45,033	1				4	[8] 33,803	8	5,168	31	6,062
Tennessee	609	554,991	6	82,072	15	104,669	67	139,109	129	86,352	392	142,789
Texas	232	1,177,436	42	943,728	9	66,799	55	123,636	39	25,256	87	18,017
Utah	58	7,591							1		57	[10] 7,591
Vermont	265	114,601					18	29,280	63	44,249	184	41,072
Virginia	1,065	735,729	13	219,333	15	107,879	81	120,997	206	138,666	750	148,854
Washington	584	5,524,509	164	4,685,418	44	314,282	187	453,905	64	42,223	125	28,681
West Virginia	398	647,055	19	319,962	22	157,015	34	72,088	68	45,601	255	52,389
Wisconsin	350	1,036,550	48	720,249	23	158,488	37	94,161	29	20,167	213	43,485
Wyoming	41	7,188							2		39	[11] 7,188

[4] Includes the cut of 2 mills in class 4.
[8] Includes the cut of 1 mill in class 5.
[9] Includes the cut of 1 mill in class 3.
[10] Include the cut of 1 mill in class 2.
[11] Includes the cut of 2 mills in class 2.

LUMBER PRODUCTION BY STATES AND GROUPS.

Table 4 shows the total quantity of lumber cut in each State for every year in which an enumeration was made, from 1870 to 1920, inclusive. The rank of the leading 25 States in each year is indicated.

The figures accurately portray the fluctuations in the lumber industry for the period of 50 years covered. In 1920, with the single exception of New York, all of the 12 States showing an increase of production were west of the Great Plains. Even in the Rocky Mountains, Colorado, Nevada, Utah, and Wyoming are well past the peak of their production.

By groups of States the relative increases and decreases as compared with 1919 were as follows:

Group.	Increase per cent.	Decrease per cent.
Rocky Mountain	31	.....
Pacific	17	.....
Northeastern	.....	15
North Carolina pine	.....	15
Lake	.....	11
Southern pine	.....	10
Central	.....	9

The most remarkable increases took place in the Pacific group and the Inland Empire, which, together, cut 1,630,000,000 feet more than in 1919. Washington increased 11 per cent, Oregon 29 per cent, California (and Nevada) 18 per cent, Idaho 27 per cent, and Montana 43 per cent. Arizona shows 64 per cent increase and New Mexico 29 per cent.

In the Lake States Minnesota showed the greatest proportional decrease, with 18 per cent. In the North Carolina pine group North Carolina's output diminished 25 per cent. In the southern pine group the heaviest decreases were: In Alabama, 20 per cent; Arkansas, 18 per cent; Georgia, 15 per cent; and Florida, 12 per cent. Lousiana lost but 1 per cent. The heavy decrease in the South is attributed, in part at least, to the extremely unfavorable weather conditions, but taken in connection with the apparent decrease in the number of large mills it is at least a strong indication of a continuous decline.

TABLE 4.—*Production of lum*

[Reported quantities for each period known, except 1915–1918 and 1920, for

State.	1870		1880		1890		1899		1904	
	Rank.	Quantity (M feet).	Rank.	Quantity (M feet).	Rank.	Quantity (M feet).	Rank.	Quantity (M feet).	Rank.	Quantity (M feet).
United States	....	12,755,543	....	18,091,356	....	[1] 23,497,653	....	[2] 34,787,084	....	[1] 34,135,139
Alabama	....	97,192	20	251,851	9	586,143	12	1,096,539	11	1,243,988
Arizona	....	1,200	....	10,715	....	5,300	....	36,182	....	55,601
Arkansas	....	78,692	....	172,503	14	526,091	5	1,595,933	8	1,680,536
California	10	318,817	17	304,795	15	515,823	22	734,232	13	1,077,499
Colorado	....	13,625	....	63,792	....	79,906	....	133,746	....	141,914
Connecticut	....	56,482	....	64,427	....	48,277	....	107,594	....	69,376
Delaware	....	18,858	....	31,572	....	23,152	....	35,395	....	30,416
Florida	19	158,524	21	247,627	21	411,436	18	788,905	18	812,693
Georgia	13	245,141	9	451,788	10	572,970	7	1,308,610	12	1,135,910
Idaho	....	1,490	....	18,204	....	27,800	....	65,331	....	211,447
Illinois	12	245,910	12	334,244	....	218,938	....	381,584	....	211,545
Indiana	5	656,400	5	915,943	8	707,115	13	977,878	23	563,853
Iowa	9	325,285	10	412,578	11	568,816	....	351,769	....	281,521
Kansas	....	74,163	....	45,281	....	4,037	....	10,645	....	2,120
Kentucky	15	214,074	16	305,684	20	420,820	21	765,343	21	586,371
Louisiana	....	76,459	....	133,472	25	303,591	11	1,113,423	3	2,459,327
Maine	6	639,167	7	566,656	12	564,243	19	756,515	16	863,860
Maryland	....	96,165	....	[8] 127,336	....	81,078	....	183,393	....	166,469
Massachusetts	17	197,377	23	205,244	....	208,655	....	342,058	....	262,467
Michigan	1	2,251,613	1	4,172,572	1	4,245,717	2	3,012,057	4	2,006,670
Minnesota	14	242,390	8	563,974	4	1,079,403	3	2,341,619	5	1,942,248
Mississippi	18	160,584	....	168,747	17	452,797	10	1,202,334	7	1,727,391
Missouri	8	329,676	11	399,744	23	395,755	24	715,968	24	553,940
Montana	....	12,571	....	21,420	....	89,511	....	255,685	....	236,430
Nebraska	....	13,824	....	13,585	....	8,556	....	4,655	....	1,862
Nevada	....	35,025	....	21,545	....	.....	....	725	....	([5])
New Hampshire	11	253,434	19	292,267	....	266,890	25	562,258	25	491,591
New Jersey	24	101,829	....	109,679	....	32,285	....	72,660	....	44,058
New Mexico	....	6,909	....	11,195	....	26,112	....	30,880	....	81,113
New York	3	1,310,066	4	1,184,220	6	909,990	17	874,754	22	581,976
North Carolina	22	124,938	22	241,822	16	509,436	8	1,278,399	10	1,318,411
Ohio	7	557,237	6	910,832	13	541,076	14	957,239	....	420,905
Oklahoma	....	.....	....	.....	....	2,552	....	22,055	....	([5])
Oregon	....	75,193	....	177,171	19	444,565	23	734,181	14	987,107
Pennsylvania	2	1,629,631	2	1,733,844	3	2,113,267	4	2,321,284	6	1,738,972
Rhode Island	....	12,732	....	8,469	....	7,620	....	18,265	....	15,398
South Carolina	....	95,098	24	185,772	....	197,940	....	466,109	20	609,769
South Dakota	....	3,894	....	29,286	....	[12] 28,231	....	[12] 33,734	....	13,705
Tennessee	16	204,751	18	302,673	18	450,097	16	939,463	19	775,885
Texas	23	106,897	13	328,968	7	839,724	9	1,230,904	9	1,406,473
Utah	....	19,741	....	25,709	....	14,295	....	17,484	....	12,630
Vermont	15	241,687	14	322,942	24	370,155	....	365,869	....	337,238
Virginia	20	144,225	15	315,939	22	409,804	15	956,169	15	949,797
Washington	21	128,743	....	160,176	5	1,061,560	6	1,428,205	2	2,485,628
West Virginia	....	76,375	25	180,112	....	299,709	20	773,583	17	855,889
Wisconsin	4	1,098,199	3	1,542,021	2	2,817,200	1	3,361,943	1	2,623,157
Wyoming	....	3,260	....	2,960	....	6,415	....	16,957	....	7,990
All other	....	.....	....	.....	....	[13] 2,800	....	[13] 6,571	....	[14] 51,993
State groups:										
Northeastern	1	4,557,428	2	4,642,656	2	4,625,612	3	5,640,045	3	4,601,821
Central	3	2,284,423	3	3,349,232	4	3,033,510	4	5,511,058	5	3,968,388
Southern	4	923,489	4	1,754,956	3	3,693,304	2	8,358,703	1	10,466,318
North Carolina pine	7	364,261	5	743,533	6	1,117,180	6	2,700,677	6	2,877,977
Lake	2	3,592,202	1	6,278,567	1	8,144,320	1	8,715,619	2	6,572,075
Pacific	5	557,778	6	663,687	5	2,021,948	5	2,897,343	4	4,550,234
Rocky Mountain	8	58,796	8	153,995	8	249,339	7	556,265	7	747,125
All other	6	417,166	7	504,730	7	612,440	8	407,374	8	351,201

[1] Excludes custom mills (sawing 3,196,527 M feet in 1890).
[2] Includes both merchant and custom sawing.
[3] Mills cutting less than 50 M feet each per year excluded.
[5] Included in "all other."
[7] Includes cut of mills in Nebraska.
[8] Includes cut of mills in District of Columbia.
[9] Included with Kansas.
[10] Reported as cut of Indian Territory

ber by States; 1870 to 1920.

which years computed quantities are given, with rank of leading 25 States.]

1905		1906		1907		1908		1909		1910	
Rank.	Quantity (M feet).	Rank.	Quantity (M feet).	Rank.	Quantity (M feet).	Rank.	Quantity (M feet).	Rank.	Quantity (M feet).	Rank.	Quantity (M feet).
....	30,502,961	....	37,550,736	....	40,256,154	....	33,224,369	....	44,509,761	....	[3] 40,018,282
13	843,897	15	1,009,783	15	1,224,967	12	1,152,079	11	1,691,001	11	1,465,623
....	(5)	....	51,960	....	72,134	....	43,287	....	62,731	....	72,655
6	1,488,589	6	1,839,368	6	1,988,504	4	1,656,991	5	2,111,300	7	1,844,446
11	1,061,608	11	1,348,559	14	1,345,943	15	996,115	18	1,143,507	14	1,254,826
....	56,753	....	110,212	....	134,239	....	117,036	....	141,710	....	121,398
....	69,845	....	124,880	....	140,011	....	137,855	....	168,371	....	126,463
....	12,260	....	44,487	....	50,892	....	41,184	....	55,440	....	46,642
19	658,007	17	888,137	21	839,058	20	730,906	17	1,201,734	18	992,091
17	712,604	18	831,675	19	853,697	17	904,668	15	1,342,249	16	1,041,617
....	212,725	....	418,944	....	513,788	24	518,625	25	645,800	21	745,984
....	119,065	....	141,374	....	141,317	....	123,319	....	170,181	....	113,506
24	352,362	25	447,808	....	504,790	....	411,868	....	556,418	....	422,963
....	129,472	....	163,747	....	144,271	....	97,242	....	132,021	....	75,446
....	[7] 1,272	....	(5)	....	(5)	....	(5)	....	4,716	....	639
22	464,676	20	661,299	17	912,908	21	658,539	21	860,712	20	753,556
3	2,293,809	2	2,796,395	2	2,972,119	2	2,722,421	2	3,551,918	2	3,733,900
15	745,705	13	1,088,747	16	1,103,808	16	929,350	19	1,111,565	19	860,273
....	163,749	....	219,098	....	213,786	....	168,534	....	267,939	....	154,554
....	252,804	....	354,483	....	364,231	....	384,526	....	361,200	....	239,206
5	1,719,687	4	2,094,279	7	1,827,685	7	1,478,252	10	1,889,724	9	1,681,081
4	1,925,804	7	1,794,144	9	1,660,716	9	1,286,122	12	1,561,508	12	1,457,734
8	1,299,390	5	1,840,250	4	2,094,485	3	1,861,016	3	2,572,669	3	2,122,205
23	362,217	24	507,084	24	548,774	....	458,938	23	660,159	24	501,691
....	189,291	....	328,727	....	343,814	....	311,533	....	308,582	....	319,089
....	(9)	....	----------	....	----------	....	----------	....	(5)	....	(5)
....	(5)	....	----------	....	(5)	....	(5)	....	(5)	....	(5)
25	340,727	23	539,259	22	754,023	22	606,760	24	649,606	....	443,907
....	17,704	....	36,253	....	39,942	....	34,930	....	61,620	....	36,542
....	(5)	....	103,079	....	113,204	....	79,439	....	91,987	....	83,544
14	750,280	19	810,949	20	848,894	19	781,391	22	681,440	23	506,074
10	1,080,602	12	1,222,974	11	1,622,387	13	1,136,796	4	2,177,715	8	1,824,722
....	331,552	....	438,775	25	529,087	25	459,259	....	542,904	25	490,039
....	11,667	....	[10] 48,694	....	140,015	....	158,756	....	225,730	....	164,663
9	1,262,610	10	1,604,894	10	1,635,563	8	1,468,158	9	1,898,995	4	2,084,633
7	1,397,164	9	1,620,881	8	1,734,729	10	1,203,041	14	1,462,771	13	1,241,199
....	14,054	....	21,528	....	32,855	....	30,528	....	25,489	....	14,392
21	466,478	22	566,928	23	649,058	23	560,888	20	897,660	22	706,831
....	11,502	....	22,634	....	34,841	....	25,859	....	31,057	....	16,340
20	540,920	21	634,587	18	894,968	18	790,642	16	1,223,849	17	1,016,475
12	929,863	8	1,741,473	3	2,229,590	6	1,524,008	7	2,099,130	6	1,884,134
....	3,618	....	7,768	....	14,690	....	15,059	....	12,638	....	11,786
....	266,676	....	329,422	....	373,660	....	304,017	....	351,571	....	284,815
16	715,197	14	1,063,241	12	1,412,477	11	1,198,725	6	2,101,716	10	1,652,192
1	3,917,166	1	4,305,053	1	3,777,606	1	2,915,928	1	3,862,916	1	4,097,492
18	672,902	16	976,173	13	1,395,979	14	1,097,015	13	1,472,942	13	1,376,737
2	2,543,503	3	2,331,305	5	2,003,279	5	1,613,315	8	2,025,038	5	1,891,291
....	4,360	....	13,213	....	17,479	....	18,822	....	28,602	....	30,931
....	[15] 88,825	....	[16] 1,213	....	[17] 5,891	....	[17] 10,627	....	[18] 11,230	....	[18] 11,955
4	4,030,968	4	5,189,987	3	5,656,831	3	4,622,116	5	5,197,012	6	3,954,067
5	2,843,694	5	3,807,100	6	4,927,823	5	3,999,580	3	5,487,165	4	4,674,967
1	8,226,159	1	10,947,081	1	12,342,435	1	10,710,845	1	14,795,731	1	13,248,679
6	2,262,277	6	2,853,143	5	3,633,922	6	2,896,409	6	5,177,091	5	4,183,745
3	6,188,994	3	6,219,728	4	5,491,680	4	4,377,689	4	5,476,270	3	5,030,106
2	6,241,384	2	7,258,506	2	6,759,112	2	5,380,201	2	6,905,418	2	7,436,951
7	466,747	7	1,038,903	7	1,209,348	7	1,103,801	7	1,292,050	7	1,385,387
8	242,738	8	236,288	8	185,003	8	133,728	8	179,024	8	104,380

[12] Includes cut of mills in North Dakota.
[13] Reported as the cut of Alaska.
[14] Includes cut of Alaska, Nevada, and Oklahoma.
[15] Includes cut of Arizona, Nevada, and New Mexico.
[16] Includes cut of Kansas and a part of Oklahoma
[17] Includes cut of Kansas and Nevada.
[18] Includes cut of Nebraska and Nevada

TABLE 4.—*Production of lumber*

State.	1911		1912		1913		1914	
	Rank.	Quantity (M feet).	Rank.	Quantity (M feet).	Rank	Quantity (M feet).	Rank.	Quantity (M feet).
United States	.....	[3] 37,003,207	.....	[3] 39,158,414	.....	[3] 38,387,009	.....	[13] 37,346,023
Alabama	13	1,226,212	12	1,378,151	8	1,523,936	8	1,494,732
Arizona	.....	73,139	.....	76,287	.....	77,363	.....	78,667
Arkansas	6	1,777,303	7	1,821,811	7	1,911,647	6	1,796,780
California	14	1,207,561	14	1,203,059	13	1,183.380	12	1,303,183
Colorado	.....	95,908	.....	88,451	.....	74,602	.....	102,117
Connecticut	.....	124,661	.....	109,251	.....	93,730	.....	81,883
Delaware	.....	23,853	.....	28,285	.....	18,039	.....	25,517
Florida	16	983,824	15	1,067,525	15	1,055,047	15,	1,073,821
Georgia	19	801,611	17	941,291	17	844,284	16	1,026,191
Idaho	20	765,670	21	713,575	21	652,616	20	763,508
Illinois	.....	96,651	.....	122,528	.....	102,902	.....	66,227
Indiana	.....	360,613	.....	401,017	.....	332,993	.....	298,571
Iowa	.....	59,974	.....	46,593	.....	21,676	.....	11,443
Kansas	.....	(5)	.....	(5)	.....	(5)	.....	(5)
Kentucky	21	632,415	22	641,296	22	541.531	22	596,392
Louisiana	2	3,566,456	2	3,876,211	2	4,161,560	1	3,956,434
Maine	18	828,417	19	882,128	18	834,673	17	992,594
Maryland	.....	144,078	.....	174,320	.....	140,469	.....	162,097
Massachusetts	.....	273,317	.....	259,329	.....	224,580	.....	143,094
Michigan	10	1,466,754	10	1,488,827	12	1,222,983	13	1,214,435
Minnesota	9	1,485,015	11	1,436,726	14	1,149,704	11	1,312,230
Mississippi	3	2,041,615	3	2,381,893	3	2,610,581	3	2,280,966
Missouri	25	418,586	.....	422,470	24	416,608	25	370,571
Montana	.....	228.416	.....	272,174	.....	357,974	.....	317,842
Nebraska	.....	(5)	.....	(5)	.....	(5)	.....	(5)
Nevada	.....	(5)	.....	(5)	.....	(5)	.....	(5)
New Hampshire	.....	388,619	25	479,499	.....	309,424	24	482,744
New Jersey	.....	28,639	.....	34,810	.....	27,248	.....	48,748
New Mexico	.....	83,728	.....	82,650	.....	65,818	.....	57,167
New York	23	526,283	23	502,351	23	457,720	23	486,195
North Carolina	5	1,798,724	4	2,193,308	6	1,957,258	4	2,227,851
Ohio	24	427,161	24	499 834	25	414,943	.....	286,063
Oklahoma	.....	143,869	.....	168,806	.....	140,284	.....	200,594
Oregon	4	1,803,698	5	1,916,160	4	2,098,467	5	1,817,875
Pennsylvania	15	1,048,606	16	992,180	19	781,547	19	864,710
Rhode Island	.....	9,016	.....	14,421	.....	14,984	.....	15,902
South Carolina	22	584,872	20	816,930	20	752,184	21	701,540
South Dakota	.....	13,046	.....	20,986	.....	19,103	.....	18,744
Tennessee	17	914,579	18	932,572	16	872,311	18	885,035
Texas	8	1,681,080	6	1,902,201	5	2,081,471	7	1,554,005
Utah	.....	10,573	.....	9,055	.....	5,403	.....	8,680
Vermont	.....	239,254	.....	235,983	.....	194,647	.....	249,608
Virginia	12	1,359,790	8	1,569,997	10	1,273,953	9	1,488,070
Washington	1	4,064,754	1	4,099,775	1	4,592,053	2	3,946,189
West Virginia	11	1,387,786	13	1,318,732	11	1,249,559	14	1,118,480
Wisonsin	7	1,761,986	9	1,498,876	9	1,493,353	10	1,391,001
Wyoming	.....	33,309	.....	13,560	.....	12,940	.....	11,852
All other	.....	[19] 11,786	.....	[19] 22,525	.....	[19] 19,461	.....	[19] 15,672
State groups:								
Northeastern	6	3,634,743	6	3,712,557	6	3,097,061	6	3,553,092
Central	4	4,237,791	5	4,338,449	4	3,930,847	5	3,621,339
Southern	1	12,221,970	1	13,537,894	1	14,328,810	1	13,383,523
North Carolina pine	5	3,743,386	3	4,580,235	3	3,983,395	3	4,417,464
Lake	3	4,713,755	4	4,424,429	5	3,866,040	4	3,917,666
Pacific	2	7,076,013	2	7,218,994	2	7,873,900	2	7,067,247
Rocky Mountain	7	1,290,743	7	1,255,752	7	1,246,716	7	1,339,833
All other	8	84,806	8	90,104	8	60,240	8	45,859

[1] Excludes custom mills (sawing 3,196,527 M feet in 1890).
[2] Includes both merchant and custom sawing.
[3] Mills cutting less than 50 M feet each per year excluded.
[4] Includes 2,655 mills cutting less than 50 M feet each.
[5] Included in "all other."
[6] Includes cut of mills in Nevada.
[7] Includes cut of mills in Nebraska.
[8] Includes cut of mills in District of Columbia.
[9] Included with Kansas.
[11] Included with California.
[19] Includes cut of Kansas, Nebraska, and Nevada.

by States, 1870 to 1920—Continued.

1915		1916		1917		1918		1919		1920	
Rank.	Quantity (M feet).	Rank.	Quantity (M feet).	Rank.	Quantity (M feet).	Rank.	Quantity (M feet).	Rank.	Quantity (M feet).	Rank.	Quantity (M feet).
....	[3] 37,011,656	....	[3] 39,807,251	....	[3] 35,831,239	....	[3] 31,890,494	....	[2,4] 34,552,076	....	[3] 33,798,800
8	1,500,000	8	1,720,000	7	1,555,000	9	1,270,000	5	1,798,746	7	1,439,200
....	75,915	....	93,270	....	79,022	....	83,661	....	73,655	....	121,196
5	1,800,000	7	1,910,000	5	1,765,000	5	1,470,000	6	1,772,157	6	1,452,200
11	[6] 1,130,000	11	[6] 1,420,000	9	[6] 1,417,068	7	[6] 1,277,084	9	1,259,363	5	[6] 1,513,000
....	74,500	....	77,580	....	71,500	....	56,882	....	64,864	....	70,000
....	90,000	....	75,000	....	66,000	....	64,000	....	86,708	....	71,600
....	25,000	....	12,000	....	8,500	....	6,000	....	27,437	....	19,800
12	1,110,000	10	1,425,000	11	1,230,000	12	950.000	10	1,137,432	12	1,000,900
17	1,000,000	16	1,000,000	19	740,000	21	515,000	13	893,965	15	761,800
21	777,000	19	849,600	17	760,000	15	802,529	16	765,388	13	970,000
....	110,000	....	60,000	....	45,000	....	42,000	....	64,628	....	56,900
....	350,000	....	270,000	....	240,000	....	250,000	....	282,487	....	258,300
....	35,000	....	20,000	....	13,436	....	14,200	....	18,493	....	14,300
....	(3)	....	534	....	4,255	....	[7] 8,401	....	2,840	....	[7] 4,500
22	560,000	22	525,000	23	360,000	23	340,000	22	512,078	22	421,100
2	3,900,000	2	4,200,000	2	4,210,000	2	3,450,000	2	3,163,871	3	3,120,000
16	1,000,000	17	935,000	16	770,000	17	650,000	21	596,116	21	505,600
....	165,000	....	90,237	....	68,000	....	71,000	....	113,362	....	85,600
....	250,000	....	210.000	....	155,000	....	175,000	....	166,841	....	139,200
13	1,100,000	13	1,230,000	13	1,065,000	13	940,000	14	875,891	16	749,800
14	1,100,000	15	1,220,000	12	1,075,000	11	1,605,000	18	699,639	19	576,300
3	2,300,000	3	2,730,000	4	2,425,000	4	1,935,000	4	2,390,135	4	2,224,000
....	350,000	....	260,000	....	275,000	....	273,000	25	321,383	25	274,200
....	328,000	25	383,900	24	350,000	24	340,000	....	287,378	24	410,000
....	(3)	....	(3)	....	.....	....	(9)	....	505	....	(9)
....	(11)	....	(11)	....	(11)	....	(11)	....	20,335	....	(11)
23	500,000	24	385,000	25	290,000	22	350,000	24	338,777	....	248,600
....	45,000	....	40,000	....	25,000	....	19,500	....	36,888	....	23,300
....	65,787	....	91,600	....	93,000	....	88,915	....	86,808	....	112,240
24	475,000	23	400,000	22	360,000	25	335,000	23	357,764	23	410,900
4	2,090,000	5	2,100,000	8	1,460,000	10	1,240,000	7	1,654,435	9	1,246,700
25	400,000	....	280,000	....	225,000	....	235,000	....	280,076	....	247,400
....	230,000	....	240,000	....	240,000	....	195,000	....	168,403	....	163,400
7	1,690,000	4	2,222,000	3	2,585,000	3	2,710,250	3	2.577,403	2	3,317,000
18	950,000	20	750,000	21	565,000	20	530,000	19	630,471	20	520,000
....	15,000	....	18,000	....	10,646	....	13,100	....	11,030	....	8,900
19	800,000	18	857,000	18	745,000	19	545,000	20	621,679	18	610,500
....	22,562	....	29,650	....	29,045	....	29,533	....	42,970	....	45,100
20	800,000	21	700,000	20	630,000	18	630,000	15	792,132	14	779,800
6	1,750,000	6	2,100,000	6	1,735,000	6	1,350,000	8	1,379,774	8	1,328,800
....	10,892	....	9,385	....	8,567	....	9,815	....	11,917	....	7,750
....	260,000	....	200,000	....	170,000	....	160,000	....	218,479	....	164,500
9	1,500,000	12	1,335,000	14	1,060,000	14	855,000	12	1,098,038	11	1,014,400
1	3,950,000	1	4,494,000	1	4,568,500	1	4,603,123	1	4,961,220	1	5,525,000
15	1,100,000	14	1,220,000	15	890,000	16	720,000	17	763,103	17	697,600
10	1,210,000	9	1,600,000	10	1,385,000	8	1,275,000	11	1,116,338	10	1,059,900
....	17,000	....	18,495	....	8,700	....	7,501	....	8,674	....	7,550
....	(3)	....	(3)	....	.....	....	.....	....	.....	....	.....
4	3,775,000	6	3,115,237	6	2,488,146	6	2,373,600	6	2,583,873	6	2,198,000
5	3,670,000	5	3,315,000	5	2,665,000	5	2,490,000	4	3,015,887	4	2,735,300
1	13,590,000	1	15,325,000	1	13,900,000	1	11,135,000	1	12,704,483	1	11,490,300
3	4,390,000	3	4,292,000	4	3,265,000	4	2,640,000	3	3,374,152	3	2,871,600
6	3,410,000	4	4,050,000	3	3,525,000	3	3,220,000	5	2,691,868	5	2,386,000
2	6,770,000	2	8,136,000	2	8,570,568	2	8,590,457	2	8,818,321	2	10,355,000
7	1,349,094	7	1,523,830	7	1,370,789	7	1,389,303	7	1,298,684	7	1,698,700
8	57,562	8	50,184	8	46,736	8	52,134	8	64,808	8	63,900

Northeastern: Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont.
Central: Illinois, Indiana, Kentucky, Missouri, Ohio, Tennessee, West Virginia.
Southern: Alabama, Arkansas, Florida, Georgia, Louisiana, Mississippi, Oklahoma, Texas.
North Carolina Pine: North Carolina, South Carolina, Virginia.
Lake: Michigan, Minnesota, Wisconsin.
Pacific: California, Nevada, Oregon, Washington.
Rocky Mountain: Arizona, Colorado, Idaho, Montana, New Mexico, Utah, Wyoming.
All other: Iowa, Kansas, Nebraska, South Dakota.

TABLE 4A.—*Value of lumber produced, by States, 1840, 1850, and 1860, compared with 1920.*

State.	1840		1850		1860		1920	
	Rank.	Value.	Rank.	Value.	Rank.	Value.	Rank.	Value.
United States		$12,943,507		$58,521,976		$93,338,606		$1,298,899,107
Alabama	20	169,008	16	1,103,481	17	1,873,484	8	45,708,992
Arizona								4,539,865
Arkansas	19	176,617		122,918		1,155,902	6	56,722,932
California			20	959,485	8	3,943,881	5	60,459,480
Colorado								2,008,300
Connecticut		147,841		534,794		572,731		2,548,960
Delaware		5,562		236,863		276,161		580,140
Florida		20,346		391,034		1,476,645	13	37,934,110
Georgia		114,050		923,403	12	2,412,996	18	23,600,564
Idaho							14	37,694,200
Illinois	16	203,666	11	1,324,484	10	2,543,985		2,215,269
Indiana	8	420,791	6	2,195,351	7	4,271,605		14,426,055
Iowa		50,280		470,760	16	2,124,502		583,011
Kansas						1,550,737		[4] 617,737
Kentucky		130,329	8	1,502,434	11	2,463,085		17,627,246
Louisiana		66,106	13	1,129,677		1,575,995	2	137,155,200
Maine	2	1,808,683	3	5,872,573	4	6,598,565		18,398,784
Maryland	14	226,977		[1] 614,168		[1] 626,989		2,865,888
Massachusetts	11	344,845	7	1,552,265	13	2,218,144		4,279,008
Michigan	9	392,325	5	2,464,329	3	7,040,190	15	34,483,302
Minnesota				57,800		1,234,203	20	20,850,534
Mississippi	18	192,794		913,197	18	1,823,627	4	82,421,440
Missouri		70,355	9	1,479,124	9	3,074,226		10,293,468
Montana								13,509,500
Nebraska						335,340		[4] 13,568
Nevada								(5)
New Hampshire	7	433,217	17	1,099,492		1,208,629		8,412,624
New Jersey	12	271,591	14	1,123,052	20	1,608,610		983,027
New Mexico				20,000		45,150		4,265,120
New York	1	3,891,302	1	13,126,759	2	9,710,945		19,760,181
North Carolina	6	506,766	18	985,075		1,074,003	10	41,901,587
Ohio	13	262,821	4	3,864,452	5	5,158,076		12,914,280
Oklahoma								6,305,606
Oregon			10	1,355,500		690,008	3	121,070,500
Pennsylvania	3	1,150,220	2	7,729,058	1	10,743,752	19	22,994,400
Rhode Island		44,455		241,556		74,592		307,228
South Carolina	5	537,684	15	1,108,880		1,124,440	17	24,401,685
South Dakota								1,849,100
Tennessee	15	217,606		725,387	15	2,199,703	16	33,227,278
Texas				466,012	19	1,735,454	9	45,312,080
Utah				14,620		119,145		178,638
Vermont	10	346,939		618,065		901,519		6,471,430
Virginia	4	538,092	19	977,412	14	2,201,187	11	40,758,592
Washington						1,172,520	1	190,778,250
West Virginia [2]							12	38,556,352
Wisconsin	17	202,239	12	1,218,516	6	4,377,880	7	46,720,392
Wyoming								193,204
All other								
State groups: [3]								
Northeastern	1	8,671,632	1	32,748,645	1	34,540,637		87,601,670
Central	3	1,305,568	2	11,091,232	2	19,710,680	3	129,259,948
Southern	4	738,921	3	5,049,722	4	12,054,103	1	435,160,924
North Carolina Pine	2	1,582,542	5	3,071,367		4,399,630	4	107,061,864
Lake	5	594,564	4	3,740,645	3	12,652,273	5	102,054,228
Pacific				2,314,985	5	5,806,409	2	372,308,230
Rocky Mountain				34,620		164,295		62,388,827
All other		50,280		470,760		4,010,579		3,063,416

[1] Includes District of Columbia (product valued at $29,000 in 1850, and $21,125 in 1860).
[2] Part of Virginia prior to 1870.
[3] Distribution of States same as shown in Table 4.
[4] Proportional division for comparative purposes.
[5] Included with California.

Expressing the results in per cents of the total cut for each period, Table 5 shows the relative rank of the eight regional groups of States, as shown by every enumeration since 1840. The history of the lumber industry is traceable in Tables 4, 4a, and 5, since the peak production of even the oldest lumbering regions probably falls within their scope. The indications seem clear that all regions except the Pacific Coast and the Rocky Mountains are definitely past their maximum production.

TABLE 5.—*Lumber cut by groups of States, in per cent of the total.*

Group.	1850	1860	1870	1880	1890	1899	1909	1919	1920
Total	*Per ct.* 100 0	*Per ct.* 100. 0	*Per ct.* 100. 0	*Per ct.* 100. 0	*Per ct.* 100. 0	*Per ct.* 100. 0	*Per ct.* 100. 0	*Per ct.* 100. 0	*Per ct.* 100. 0
Northeastern group	54. 8	37. 0	37. 8	25. 8	19. 8	16. 3	11. 7	7. 5	6. 5
Central group	18. 6	21. 1	20. 0	18. 4	13. 1	16. 1	12. 3	8. 7	8. 1
Southern group	8. 5	13. 0	6. 9	9. 7	15. 6	24. 0	33. 3	36. 8	34. 0
North Carolina pine group	5. 1	4. 8	2. 5	4. 1	4. 7	7. 7	11. 6	9. 8	8. 5
Lake States group	6. 3	13. 6	24. 4	34. 7	34. 6	24. 9	12. 3	7. 8	7. 1
Pacific group	5. 9	6. 4	4. 0	3. 6	8. 5	8. 3	15. 5	25. 5	30. 6
Rocky Mountain group	.0	.1	.9	.9	1. 1	1. 6	2. 9	3. 7	5. 0
All other	.8	4. 0	3. 5	2. 8	2. 6	1. 1	.4	.2	.2

Northeastern group: Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont.
Central group: Illinois, Indiana, Kentucky, Missouri, Ohio, Tennessee, West Virginia.
Southern group: Alabama, Arkansas, Florida, Georgia, Louisiana, Mississippi, Oklahoma, Texas.
North Carolina pine group: North Carolina, South Carolina, Virginia.
Lake States group: Michigan, Minnesota, Wisconsin.
Pacific group: California, Nevada, Oregon, Washington.
Rocky Mountain group: Arizona, Colorado, Idaho, Montana, New Mexico, Utah, Wyoming.
All other: Iowa, Kansas, Nebraska, South Dakota.

LUMBER PRODUCTION BY SPECIES.

Table 6 gives the lumber production by species, from 1899, the earliest enumeration in which species were distinguished. Computed figures, so far as available, have been used. The rank of the first 15 species is shown for each year. The species showing the principal increases in production in 1920 are from the Pacific coast and Rocky Mountains.

TABLE 6.—*Production of lum*

[Reported quantities for each period known, except 1915–1918 and 1920, for which

Species or kind of wood.	1899		1904		1905		1906	
	Rank.	Quantity (M feet).	Rank.	Quantity (M feet).	Rank.	Quantity (M feet).	Rank.	Quantity (M feet).
Total	.....	34,787,084	.....	34,135,139	.....	30,502,961	.....	37,550,736
Softwoods	.....	26,153,063	.....	27,353,312	.....	24,914,618	.....	30,235,245
Yellow pine	1	9,658,548	1	11,533,070	1	8,771,966	1	11,661,077
Douglas fir	5	1,736,507	4	2,928,409	3	4,319,479	2	4,969,843
White pine	2	7,772,391	2	5,332,704	2	4,983,698	3	4,583,727
Hemlock	4	3,420,673	3	3,268,787	4	2,804,083	4	3,537,329
Western yellow pine	8	944,560	7	1,279,237	7	988,542	7	1,386,777
Spruce	6	1,448,091	6	1,303,886	6	1,165,940	6	1,644,987
Cypress	10	495,836	9	749,592	8	753,369	9	839,276
Redwood	13	360,167	12	519,267	11	411,689	11	659,678
Cedar	.....	232,978	.....	223,035	12	363,900	.....	357,845
Larch	.....	50,619	.....	31,784	.....	140,636	.....	289,473
White fir	.....	.....	.....	.....	.....	52,725	.....	104,329
Sugar pine	.....	53,558	.....	.....	.....	123,085	.....	133,640
Balsam fir	.....	.....	.....	.....	.....	35,506	.....	.....
Lodgepole pine	.....	.....	.....	.....	.....	.....	.....	.....
All other softwoods	.....	9,135	.....	183,541	.....	.....	.....	67,264
Hardwoods	.....	8,634,021	.....	6,781,827	.....	5,588,343	.....	7,315,491
Oak	3	4,438,027	5	2,902,855	5	1,833,769	5	2,820,393
Maple	9	633,466	10	587,558	9	608,746	8	882,878
Gum, red and sap	15	285,417	11	523,990	13	316,588	12	453,678
Yellow poplar	7	1,115,242	8	853,554	10	582,748	10	683,132
Chestnut	.....	206,688	15	243,537	.....	224,413	13	407,379
Birch	.....	132,601	.....	224,009	15	240,704	15	370,432
Beech	.....	.....	.....	.....	.....	219,000	.....	275,661
Basswood	14	308,069	.....	228,041	14	258,390	14	376,838
Elm	11	456,731	14	258,330	.....	227,038	.....	224,795
Cottonwood	12	415,124	13	321,574	.....	236,000	.....	263,996
Ash	.....	269,120	.....	169,178	.....	159,634	.....	214,460
Hickory	.....	96,636	.....	106,824	.....	95,803	.....	148,212
Tupelo	.....	.....	.....	.....	.....	35,794	.....	47,882
Walnut	.....	38,681	.....	31,455	.....	29,851	.....	48,174
Sycamore	.....	29,715	.....	18,002	.....	.....	.....	.....
Cherry	.....	.....	.....	.....	.....	.....	.....	.....
All other hardwoods	.....	208,504	.....	312,920	.....	[2] 519,865	.....	97,581
Minor species	.....	.....	.....	.....	.....	.....	.....	.....

[1] Includes a small quantity of softwoods in New York not separately reported.

ber, by species, 1899 to 1920.

years computed quantities are given, with rank of 15 leading kinds of wood.]

1907		1908		1909		1910		1911	
Rank.	Quantity (M feet).	Rank.	Quantity (M feet).	Rank.	Quantity (M feet).	Rank.	Quantity (M feet).	Rank.	Quantity (M feet).
.....	40,256,154	.....	33,224,369	.....	44,509,761	.....	40,018,282	.....	37,003,207
.....	31,001,225	.....	25,546,006	.....	33,896,959	.....	31,160,856	.....	28,902,388
1	13,215,185	1	11,236,372	1	16,277,135	1	14,143,471	1	12,896,706
2	4,748,872	2	3,675,114	2	4,856,378	2	5,203,644	2	5,054,243
3	4,192,708	3	3,344,921	4	3,900,034	4	3,352,183	3	3,230,584
5	3,373,016	5	2,530,843	5	3,051,399	5	2,836,129	5	2,555,308
7	1,527,195	7	1,275,550	7	1,499,985	6	1,562,106	6	1,330,700
6	1,726,797	6	1,411,992	6	1,748,547	7	1,449,912	7	1,261,728
10	757,639	9	743,297	9	955,635	9	935,659	8	981,527
13	569,450	14	404,802	13	521,630	12	543,493	13	489,768
.....	251,002	.....	272,764	.....	346,008	.....	415,039	.....	374,925
.....	324,509	.....	382,466	15	421,214	.....	382,514	.....	368,216
.....	146,508	.....	98,120	.....	89,318	.....	132,327	.....	124,307
.....	115,005	.....	99,809	.....	97,191	.....	103,165	.....	117,987
.....	[1] 53,339	.....	69,956	.....	108,702	.....	74,580	.....	83,375
.....	.....	.....	.....	.....	23,733	.....	26,634	.....	33,014
.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
.....	9,254,929	.....	7,678,363	.....	10,612,802	.....	8,857,426	.....	8,100,819
4	3,718,760	4	2,771,511	3	4,414,457	3	3,522,098	4	3,098,444
8	939,073	8	874,983	8	1,106,604	8	1,006,637	9	951,667
11	689,200	11	589,347	11	706,945	11	610,208	11	582,967
9	862,849	10	654,122	10	858,500	10	734,926	10	659,475
12	653,239	12	539,341	12	663,891	13	535,049	12	529,022
15	387,614	15	386,367	.....	452,370	15	420,769	14	432,571
14	430,005	13	410,072	14	511,244	14	437,325	15	403,881
.....	381,088	.....	319,505	.....	399,151	.....	344,704	.....	304,621
.....	260,579	.....	273,845	.....	347,456	.....	265,107	.....	236,108
.....	293,161	.....	232,475	.....	265,600	.....	220,305	.....	198,629
.....	252,040	.....	225,367	.....	291,209	.....	246,035	.....	214,398
.....	203,211	.....	197,372	.....	333,929	.....	272,252	.....	240,217
.....	68,842	.....	69,170	.....	96,676	.....	92,071	.....	98,142
.....	41,490	.....	43,681	.....	46,108	.....	36,449	.....	38,293
.....	46,044	.....	43,332	.....	56,511	.....	45,063	.....	42,836
.....	9,087	.....	18,054	.....	24,594	.....	18,237	.....	21,422
.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
.....	18,647	.....	29,819	.....	37,557	.....	50,191	.....	48,126

[1] Reported as "Mixed" and probably includes some softwoods.

TABLE 6.—*Production of lumber*

	1912		1913		1914		1915	
Total		39,158,414		38,387,009		37,346,023		37,011,656
Softwoods		30,526,416		30,302,549		29,406,839		29,484,763
Yellow pine	1	14,737,052	1	14,839,363	1	14,472,804	1	14,700,000
Douglas fir	2	5,175,123	2	5,556,096	2	4,763,693	2	4,431,249
White pine	4	3,138,227	4	2,568,636	4	2,632,587	4	2,700,000
Hemlock	5	2,426,554	5	2,319,982	5	2,165,728	5	2,275,000
Western yellow pine	7	1,219,444	6	1,258,528	6	1,327,365	7	1,293,985
Spruce	6	1,238,600	8	1,046,816	7	1,245,614	6	1,400,000
Cypress	9	997,227	7	1,097,247	8	1,013,013	8	1,100,000
Redwood	13	496,796	12	510,271	12	535,199	13	420,294
Cedar		329,000		358,444	14	499,903	14	420,000
Larch	15	407,064	14	395,273		358,561		375,000
White fir		122,613		88,109		112,627		125,048
Sugar pine		132,416		149,926		136,159		117,701
Balsam fir		84,261		93,752		125,212		100,000
Lodgepole pine		22,039		20,106		18,374		26,486
Hardwoods		8,631,998		8,084,460		7,939,184		7,526,893
Oak	3	3,318,952	3	3,211,718	3	3,278,908	3	2,970,000
Maple	8	1,020,864	9	901,487	9	909,743	9	900,000
Gum, red and sap	10	694,260	10	772,514	10	675,380	10	655,000
Yellow poplar	11	623,289	11	620,176	13	519,221	12	464,000
Chestnut	12	554,230	13	505,802	11	540,591	11	490,000
Birch		388,272	15	378,739	15	430,667	15	415,000
Beech	14	435,250		365,501		376,464		360,000
Basswood		296,717		257,102		264,656		260,000
Elm		262,141		214,532		214,294		210,000
Cottonwood		227,477		208,938		195,198		180,000
Ash		234,548		207,816		189,499		190,000
Hickory		278,757		162,980		116,113		100,000
Tupelo		122,545		120,420		124,480		170,000
Walnut		43,083		40,565		25,573		90,000
Sycamore		49,468		30,804		22,773		25,000
Cherry		22,245		14,126				
Minor species		59,900		71,240		55,624		47,893

by species, 1899 to 1920—Continued.

1916		1917		1918		1919		1920	
.....	39,807,251	.....	35,831,239	.....	31,890,494	.....	34,552,076	.....	33,798,800
.....	31,331,900	.....	29,174,122	.....	25,667,531	.....	27,407,130	.....	26,809,500
1	15,055,000	1	13,539,464	1	10,845,000	1	13,062,938	1	11,091,000
2	5,416,000	2	5,585,000	2	5,820,000	2	5,902,169	2	6,960,000
4	2,700,000	3	2,250,000	3	2,200,000	6	1,723,642	6	1,500,000
5	2,350,000	5	2,200,000	5	1,875,000	5	1,754,998	5	1,850,000
6	1,690,000	6	1,960,000	6	1,710,000	4	1,755,015	4	2,290,000
7	1,250,000	7	1,125,000	7	1,125,000	7	979,968	9	825,000
8	1,000,000	8	950,000	10	630,000	10	656,212	10	625,000
13	490,850	11	487,458	11	443,231	12	410,442	11	476,500
.....	410,000	.....	265,000	.....	245,000	.....	332,234	.....	260,000
14	455,000	14	360,000	14	355,000	13	338,121	14	390,000
.....	190,000	.....	218,200	.....	213,000	.....	223,422	.....	280,000
.....	169,250	.....	132,600	.....	111,800	.....	133,658	.....	146,000
.....	125,000	.....	88,900	.....	82,000	.....	68,030	.....	85,000
.....	30,800	.....	12,500	.....	12,500	.....	16,281	.....	31,000
.....	8,475,351	.....	6,657,117	.....	6,222,963	.....	7,144,946	.....	6,989,300
3	3,300,000	4	2,250,000	4	2,025,000	3	2,708,280	3	2,500,000
9	975,000	9	860,000	8	815,000	8	857,489	7	875,000
10	800,000	10	788,000	9	765,000	9	851,431	8	850,000
11	560,000	15	350,000	15	290,000	.....	328,538	15	350,000
12	535,000	13	415,000	12	400,000	11	545,696	12	475,000
15	450,000	12	415,000	13	370,000	14	375,079	13	405,000
.....	360,000	.....	296,000	15	290,000	15	358,985	.....	325,000
.....	275,000	.....	203,000	.....	200,000	.....	183,562	.....	195,000
.....	240,000	.....	205,000	.....	195,000	.....	194,417	.....	225,000
.....	200,000	.....	190,000	.....	175,000	.....	144,155	.....	155,000
.....	210,000	.....	175,000	.....	170,000	.....	154,931	.....	170,000
.....	125,000	.....	95,000	.....	100,000	.....	170,013	.....	150,000
.....	275,000	.....	265,000	.....	237,000	.....	143,730	.....	180,000
.....	90,000	.....	62,000	.....	100,000	.....	39,218	.....	35,000
.....	40,000	.....	32,000	.....	30,000	.....	28,114	.....	31,000
.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
.....	40,351	.....	56,117	.....	60,963	.....	61,308	.....	68,300

Figures 13 and 14 supplement Tables 4 and 6 by showing graphically the computed 1920 lumber production, by States and by species, respectively.

The several woods which go to make up the bulk of the lumber cut in the United States are treated individually in the following

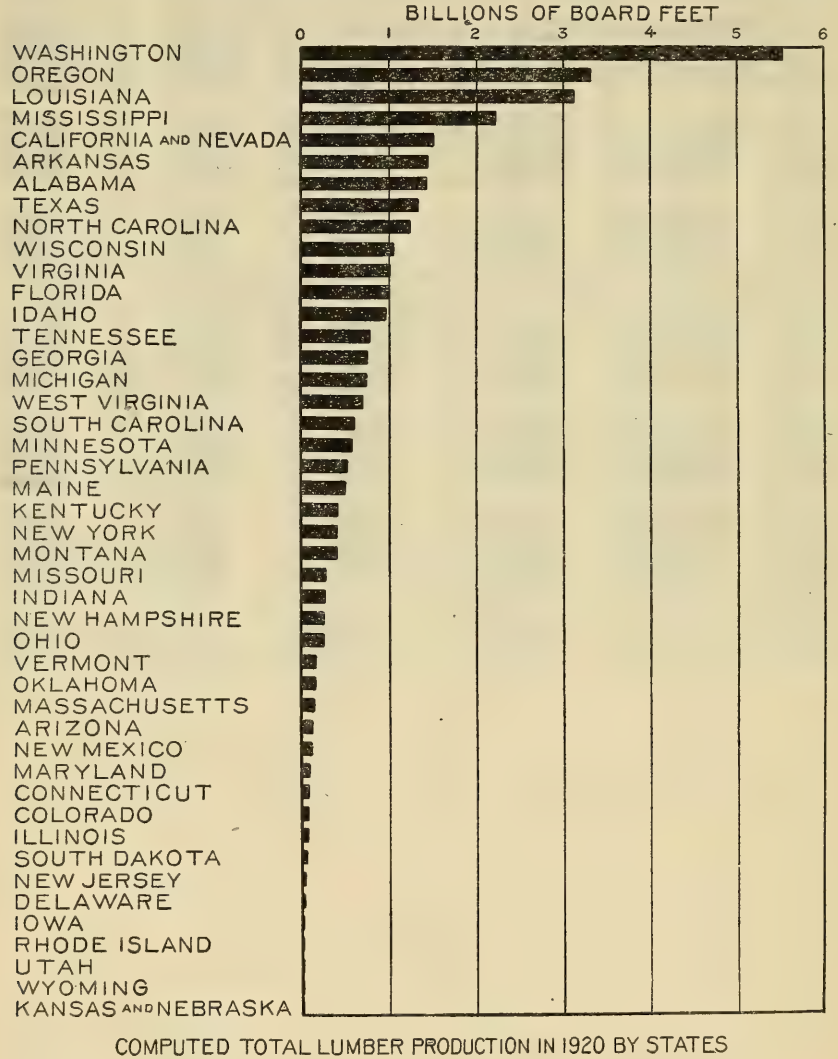


FIG. 13.—The three Pacific Coast States now stand among the first five in point of production.

pages. The tabulation for each species shows by States the number of active mills reporting, the quantity reported cut, the proportion of the total reported cut, the average value per thousand feet f. o. b. mill, and the computed total cut.

The question is frequently asked in connection with lumber production figures as to what part shortleaf pine forms of the total

quantity of yellow pine reported, or the ratio of white oak cut to the total. It is not practicable in lumber census work to do more than group the figures for all of the yellow pines together, and treat the

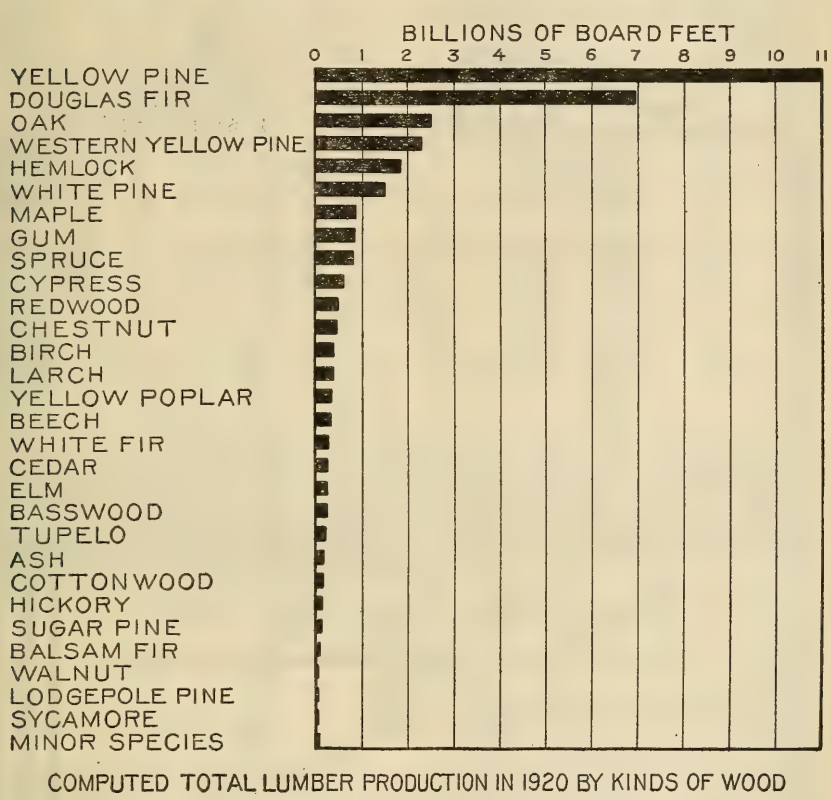


FIG. 14.—The predominance of valuable softwoods in North American forests was one of the reasons for the rapid economic development of the United States.

oaks, gums, cedars, and other woods in the same way, since no standard classification is found among the lumbermen. Producers in different sections frequently apply different local names to the same species, and only confusion would follow an attempt to segregate the figures.

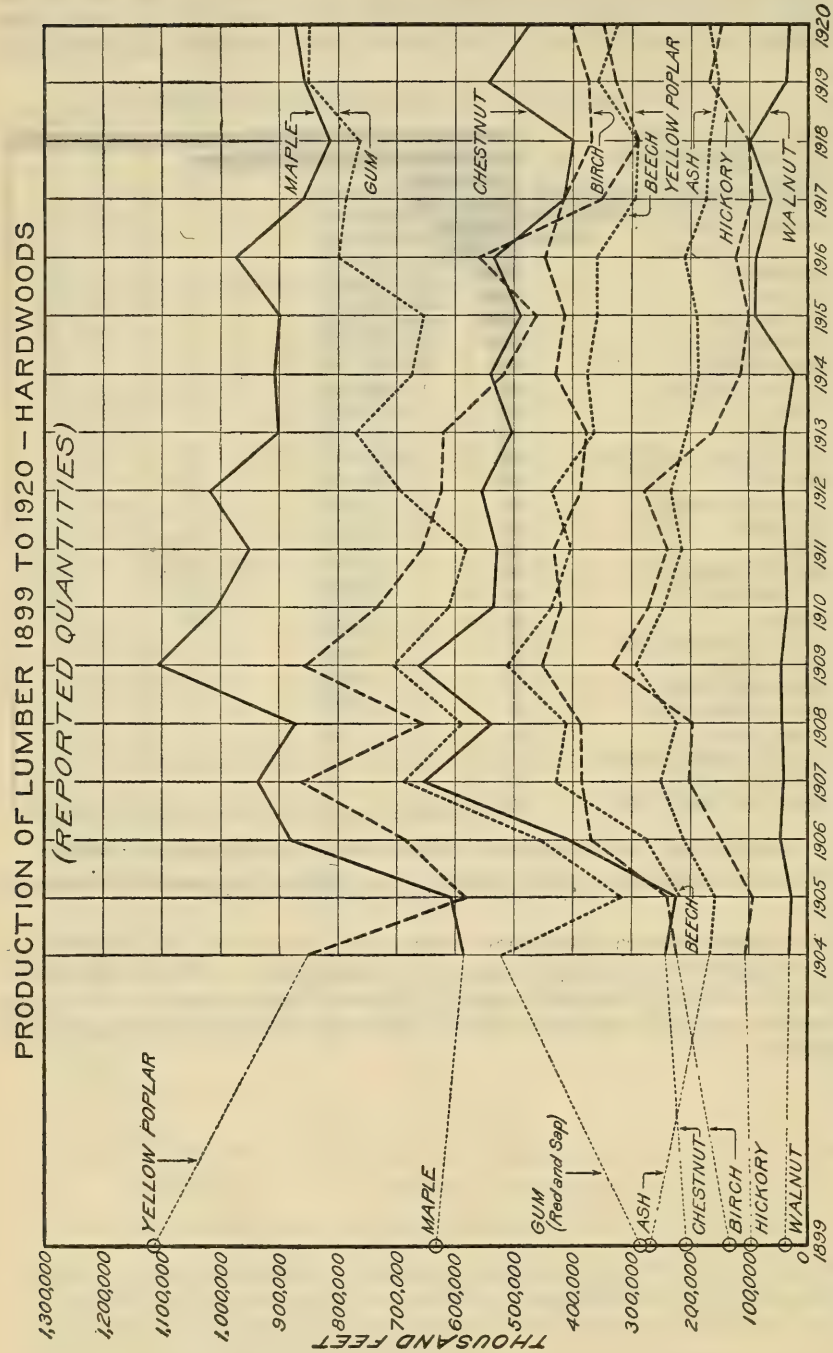


FIG. 15.—Gum is the only hardwood showing a definite tendency to increase in production. There is practically no hardwood in the Western States.

TABLE 7.—*Reported production of yellow pine* [1] *lumber in 1920.*

[Computed total production in the United States, 11,091,000 M feet.]

State.	Number of active mills reporting.	Quantity reported.		Average value per 1,000 feet f. o. b. mill.
		M feet b. m.	Per cent.	
United States	6,014	8,964,313	100.0	$35.89
Louisiana	202	2,066,263	23.0	42.50
Mississippi	549	1,322,958	14.8	36.67
Texas	221	1,125,015	12.6	33.81
Alabama	872	985,773	11.0	31.44
Florida	196	744,373	8.3	35.77
Arkansas	361	586,369	6.5	36.77
North Carolina	1,053	517,425	5.8	29.88
Georgia	694	478,547	5.3	26.84
South Carolina	367	436,246	4.9	39.06
Virginia	731	404,804	4.5	33.48
Oklahoma	48	135,280	1.5	37.60
Tennessee	292	74,167	.8	25.16
Maryland	149	35,360	.4	29.71
Missouri	92	23,693	.3	25.57
All other States (see Table 37, p. 56)	187	28,040	.3	27.43

[1] Longleaf pine (*Pinus palustris*), also known as Georgia pine and hard pine and exported as pitch pine; cut mostly in the Gulf States. North Carolina pine (*P. taeda*), also called shortleaf, loblolly, old field, rosemary, and Virginia pine; cut mostly in Virginia, North and South Carolina, Arkansas, and Texas. Shortleaf pine (*P. echinata*); cut mostly in Virginia, North and South Carolina, Arkansas, Missouri, Louisiana, and Mississippi. Sand pine (*P. clausa*); Florida and Alabama. Slash (or Cuban) pine (*P. heterophylla*); cut mostly in Georgia and the Gulf States east of the Mississippi River. Scrub pine (*P. virginiana*), also called Jersey pine; cut in the Middle Atlantic States. Pitch pine (*P. rigida*); Middle Atlantic and Northern States. Spruce pine (*P. glabra*); Gulf States. Pond pine (*P. serotina*); South Atlantic States. Table-Mountain pine (*P. pungens*); Appalachian Mountains.

TABLE 8.—*Reported production of Douglas fir* [1] *lumber, 1920.*

[Computed total production in the United States, 6,960,000 M feet.]

State.	Number of active mills reporting.	Quantity reported.		Average value per 1,000 feet f. o. b. mill
		M feet b. m.	Per cent.	
United States	1,403	6,956,683	100.0	$34.59
Washington	464	4,275,017	61.5	34.94
Oregon	527	2,347,368	33.7	34.80
California	101	161,632	2.3	30.50
Idaho	131	105,786	1.5	25.09
Montana	84	55,670	.8	29.73
All other States (see Table 37, p. 56)	96	11,210	.2	31.16

[1] Douglas fir (*Pseudotsuga taxifolia*) is the principal commercial species.

TABLE 9.—*Reported production of oak*[1] *lumber in 1920.*

[Computed total production in the United States, 2,500,000 M feet.]

State.	Number of active mills reporting.	Quantity reported.		Average value per 1,000 feet f. o. b. mill.
		M feet b. m.	Per cent.	
United States	8,552	1,853,580	100.0	$46.88
Arkansas	477	225,422	12.2	43.42
Tennessee	551	221,260	11.9	46.00
West Virginia	383	202,499	10.9	59.51
Virginia	813	166,667	9.0	51.07
Kentucky	532	141,588	7.6	44.25
Mississippi	320	115,399	6.2	41.35
Missouri	377	101,667	5.5	36.95
Louisiana	104	92,725	5.0	39.84
Pennsylvania	715	88,729	4.8	45.11
Ohio	454	85,131	4.6	54.21
North Carolina	625	82,671	4.5	45.07
Indiana	375	79,640	4.3	62.74
Alabama	425	46,646	2.5	33.26
New York	625	32,157	1.7	53.88
Texas	73	27,074	1.5	42.43
Georgia	239	26,003	1.4	37.79
All other States (see Table 37, p. 56)	1,464	118,302	6.4	43.41

[1] Commercially the oaks are classed as white and red. The principal commercial oaks are as follows: *White oaks.*—White oak (*Quercus alba*) is the white oak common throughout the eastern half of the United States; chestnut (or rock) oak (*Q. prinus*) is found in the Appalachian region; post oak (*Q. minor*) and bur oak (*Q. macrocarpa*) are common throughout the eastern half of the country; overcup oak (*Q. lyrata*) and cow (or basket) oak (*Q. michauxii*) are the principal southern white oaks. *Red oaks.*—Red oak (*Q. rubra*) is the red oak common in the eastern part of the United States; Texan oak (*Q. texana*) is the principal red oak sawed in the lower Mississippi Valley; pin oak (*Q. palustris*) is found in the Eastern and Central States; scarlet oak (*Q. coccinea*) is the northern and northeastern red oak; yellow (or black) oak (*Q. velutina*) is common in most States east of the Rocky Mountains; willow oak (*Q. phellos*) is cut mostly in the Southern States.

TABLE 10.—*Reported production of western yellow pine*[1] *lumber, 1920.*

[Computed total production in the United States, 2,290,000 M feet.]

State.	Number of active mills reporting.	Quantity reported.		Average value per 1,000 feet f. o. b. mill.
		M feet b. m.	Per cent.	
United States	900	2,270,898	100.0	$38.73
Oregon	180	630,326	27.8	44.03
California, including Nevada	141	509,471	22.4	37.50
Idaho	124	366,857	16.1	35.97
Washington	148	278,573	12.3	37.34
Montana	67	173,507	7.6	34.78
Arizona	19	119,406	5.3	37.48
New Mexico	53	104,059	4.6	38.22
South Dakota	44	45,033	2.0	41.00
Colorado	81	37,191	1.6	27.22
All other States (see Table 37, p. 56)	43	6,475	.3	23.71

[1] Western yellow pine (*Pinus ponderosa*) is the one species cut as such.

TABLE 11.—*Reported production of hemlock*[1] *lumber, 1920.*

[Computed total production in the United States, 1,850,000 M feet.]

State.	Number of active mills reporting.	Quantity reported.		Average value per 1,000 feet f. o. b. mill.
		M feet b. m.	Per cent.	
United States	3,001	1,685,320	100.0	$32.05
Washington	124	495,444	29.4	27.90
Wisconsin	213	403,325	23.9	31.61
Michigan	176	206,840	12.3	31.58
Pennsylvania	334	134,740	8.0	44.69
Oregon	47	89,130	5.3	25.73
West Virginia	91	85,408	5.1	41.98
New York	946	74,004	4.4	38.99
Maine	310	54,726	3.3	31.09
North Carolina	76	33,271	2.0	30.64
Tennessee	57	32,721	1.9	29.07
New Hampshire	143	23,508	1.4	30.36
Vermont	203	17,330	1.0	34.11
Virginia	65	16,992	1.0	37.46
Massachusetts	94	7,105	.4	29.19
Kentucky	43	6,775	.4	26.05
All other States (see Table 37, p. 56)	79	4,001	.2	32.27

[1] Hemlock (*Tsuga canadensis*) is cut in the Lake States, Northeastern States, and the Appalachian region. Western hemlock (*T. heterophylla*) is cut in Washington and Oregon. Mountain hemlock (*T. mertensiana*) is cut in small quantities. Carolina hemlock (*T. caroliniana*) is occasionally cut in the Appalachian region.

TABLE 12.—*Reported production of white pine*[1] *lumber in 1920.*

[Computed total production in the United States 1,500,000 M feet.

State.	Number of active mills reporting.	Quantity reported.		Average value per 1,000 feet f. o. b. mill.
		M feet b. m.	Per cent.	
United States	2,769	1,377,327	100.0	$41.49
Minnesota	170	429,210	31.2	37.45
Idaho	36	261,251	19.0	53.92
Maine	347	165,102	12.0	33.94
New Hampshire	195	121,202	8.8	32.07
Wisconsin	207	88,979	6.5	49.20
Washington	38	69,051	5.0	45.02
New York	725	66,311	4.8	46.79
Massachusetts	164	57,905	4.2	30.26
Michigan	129	36,186	2.6	48.07
Pennsylvania	337	29,004	2.1	48.12
Vermont	88	13,827	1.0	41.14
West Virginia	51	6,163	.4	40.12
Virginia	86	6,127	.4	32.97
All other States (see Table 37, p. 56)	196	27,009	2.0	36.92

[1] White pine (*Pinus strobus*) is the white pine cut in the Lake States, the Northeastern States, and the Appalachian region. Norway (or red) pine (*P. resinosa*) though botanically a yellow pine, is cut in the Lake States and largely marketed with white pine. Jack pine (*P. banksiana*) is cut in the Lake States. Western white pine (*P. monticola*) is cut in Idaho, Montana, Washington, and Oregon.

TABLE 13.—*Reported production of maple* [1] *lumber in 1920.*

[Computed total production in the United States, 875,000 M feet.]

State.	Number of active mills reporting.	Quantity reported.		Average value per 1,000 feet f. o. b. mill.
		M feet b. m.	Per cent.	
United States	4,131	768,345	100.0	$50.16
Michigan	212	279,911	36.4	54.04
Wisconsin	264	188,252	24.5	49.77
New York	857	72,724	9.5	48.38
West Virginia	186	56,630	7.4	57.26
Pennsylvania	454	39,194	5.1	47.01
Indiana	310	26,664	3.5	47.87
Ohio	342	21,817	2.8	40.01
Vermont	197	17,759	2.3	41.10
Missouri	105	8,679	1.1	40.99
New Hampshire	82	7,702	1.0	34.32
All other States (see Table 37, p. 56)	1,122	49,013	6.4	39.62

[1] Sugar (or hard) maple (*Acer saccharum*) is cut principally in the Northern States. Silver (or soft) maple (*A. saccharinum*) is also cut in the Northern States. Red (or soft) maple (*A. rubrum*) is the principal species cut in the Southern States. Broadleaf maple (*A. macrophyllum*) is cut in the Pacific coast States.

TABLE 14.—*Reported production of gum* [1] *lumber in 1920.*

[Computed total production in the United States, 850,000 M. feet.]

State.	Number of active mills reporting.	Quantity reported.		Average value per 1,000 feet f. o. b. mill.
		M feet b. m	Per cent.	
United States	2,060	684,745	100.0	$35.24
Arkansas	288	194,981	28.5	36.79
Mississippi	232	147,781	21.6	34.86
Louisiana	103	125,944	18.4	35.79
Tennessee	234	52,821	7.7	34.47
Alabama	162	33,700	4.9	29.46
South Carolina	34	20,483	3.0	35.29
Texas	55	18,033	2.6	36.33
Georgia	49	17,991	2.6	35.51
Missouri	60	17,304	2 5	37.08
Virginia	143	12,607	1.8	27.88
North Carolina	105	8,687	1.3	26.56
Kentucky	171	7,417	1.1	28.48
Florida	7	7,255	1.1	34.45
Oklahoma	6	6,546	1.0	54.60
All other States (see Table 37, p. 56)	411	13,195	1.9	32.23

[1] Red gum (*Liquidambar styraciflua*) is the only species that goes into red gum lumber. Commercial sap gum is the sapwood of the red gum.

TABLE 15.—*Reported production of spruce* [1] *lumber in 1920.*

[Computed total production in the United States, 825,000 M. feet.]

State.	Number of active mills reporting.	Quantity reported.		Average value per 1,000 feet f. o. b. mill.
		M feet b. m	Per cent.	
United States	1,241	805,320	100.0	$38.94
Washington	75	192,671	23.9	37.70
Oregon	39	165,418	20.5	37.03
Maine	244	164,652	20.5	40.65
West Virginia	11	48,121	6.0	46.23
New Hampshire	94	43,835	5.4	39.80
North Carolina	9	33,588	4.2	42.90
Minnesota	74	31,492	3.9	34.97
New York	188	27,823	3.5	44.33
Vermont	205	25,962	3.2	38.92
Montana	21	21,573	2.7	32.98
Colorado	64	13,859	1.7	32.89
Idaho	24	10,572	1.3	42.38
Michigan	67	8,686	1.1	39.79
All other States (see Table 37, p. 56)	126	17,068	2.1	32.87

[1] Red spruce (*Picea rubens*) is the principal species cut in the Northeastern States and the Appalachian region. Sitka spruce (*P. sitchensis*) is the principal species cut in Oregon and Washington. Black spruce (*P. mariana*) is cut in limited quantities in the Northeastern States. White spruce (*P. canadensis*) is cut in the Lake States, New York, and northern New England. Engelmann spruce (*P. engelmanni*) is cut in the Rocky Mountain region.

TABLE 16.—*Reported production of cypress* [1] *lumber in 1920.*

[Computed total production in the United States, 625,000 M. feet.]

State.	Number of active mills reporting.	Quantity reported.		Average value per 1,000 feet f. o. b. mill.
		M feet b. m.	Per cent.	
United States	656	571,674	100.0	$51.02
Louisiana	90	273,116	47.8	54.84
Florida	40	105,329	18.4	52.27
Georgia	59	45,863	8.0	53,18
Missouri	43	41,053	7.2	39.93
South Carolina	33	36,183	6.3	51.35
Arkansas	134	34,790	6.1	37.78
Mississippi	63	11,945	2.1	38.97
North Carolina	54	5,913	1.0	42.48
Tennessee	45	5,737	1.0	43.04
All other States (see Table 33, p. 56)	95	11,745	2.1	40.00

[1] Bald cypress (*Taxodium distichum*) is the one species cut as such.

TABLE 17.—*Reported production of redwood* [1] *lumber in 1920.*

[Computed total production in the United States, 476,500 M feet.]

State.	Number of active mills reporting.	Quantity reported.		Average value per 1,000 feet f. o. b. mill.
		M feet b. m.	Per cent.	
United States	43	476,003	100.0	$46.90
California	43	476,003	100.0	46.90

[1] Redwood (*Sequoia sempervirens*) is the species chiefly cut. Bigtree (*S. washingtoniana*) furnishes a minor part of the redwood production.

TABLE 18.—*Reported production of chestnut* [1] *lumber in 1920.*

[Computed total production in the United States, 475,000 M feet.]

State.	Number of active mills reporting.	Quantity reported.		Average value per 1,000 feet f. o. b. mill.
		M feet b. m.	Per cent.	
United States	2,977	379,675	100.0	$42.48
West Virginia	279	97,301	25.6	50.93
Virginia	421	56,103	14.8	46.86
North Carolina	157	47,170	12.4	39.42
Pennsylvania	617	45,067	11.9	37.09
Tennessee	198	32,653	8.6	42.52
Connecticut	117	22,875	6.0	35.59
New York	419	17,780	4.7	42.38
Massachusetts	110	17,682	4.7	30.50
Kentucky	258	16,011	4.2	32.40
Ohio	167	7,227	1.9	39.92
Maryland	87	5,342	1.4	34.46
New Jersey	44	3,764	1.0	46.11
Rhode Island	16	3,135	.8	32.94
Georgia	6	2,561	.7	34.57
All other States (see Table 37, p. 56)	81	5,004	1.3	32.11

[1] Chestnut (*Castanea dentata*) is the only species included in chestnut lumber.

TABLE 19.—*Reported production of birch* [1] *lumber in 1920.*

[Computed total production in the United States, 405,000 M feet.]

State.	Number of active mills reporting.	Quantity reported.		Average value per 1,000 feet f. o. b. mill.
		M feet b. m.	Per cent.	
United States	1,882	346,577	100.0	$53.44
Wisconsin	198	177,305	51.2	57.27
Michigan	128	58,866	17.0	54.88
New York	445	33,221	9.6	52.04
Maine	128	17,496	5.0	39.01
Vermont	189	15,307	4.4	42.75
West Virginia	77	10,910	3.1	69.21
New Hampshire	104	10,023	2.9	35.01
Minnesota	78	6,427	1.9	36.00
Pennsylvania	181	6,370	1.8	51.71
All other States (see Table 37, p. 56)	354	10,652	3.1	37.69

[1] Yellow birch (*Betula lutea*) is the principal species cut in the Lake States, New England, and New York. Paper birch (*B. papyrifera*) and white (or gray) birch (*B. populifolia*) are also cut to a limited extent in New England. Sweet (or cherry) birch (*B. lenta*) is cut in West Virginia and Pennsylvania. River (or red) birch (*B. nigra*) is cut in the Southern States.

TABLE 20.—*Reported production of larch* [1] *lumber in 1920.*

[Computed total production in the United States, 390,000 M feet.]

State.	Number of active mills reporting.	Quantity reported.		Average value per 1,000 feet f. o. b. mill.
		M feet b. m.	Per cent.	
United States	528	375,103	100.0	$30.28
Idaho	62	142,103	37.9	31.01
Montana	44	112,400	30.0	30.22
Washington	75	66,266	17.7	28.01
Oregon	19	17,938	4.8	31.97
Michigan	86	12,457	3.3	31.89
Wisconsin	114	11,765	3.1	28.71
Minnesota	89	11,706	3.1	31.68
All other States (see Table 37, p. 56)	39	468	.1	38.85

[1] Western larch (*Larix occidentalis*) is the species cut in the inland Empire and the Pacific Northwest. Tamarack, or larch (*L. laricina*), is cut in the Lake States and New England.

TABLE 21.—*Reported production of yellow poplar* [1] *lumber in 1920.*

[Computed total production in the United States, 350,000 M feet.]

State.	Number of active mills reporting.	Quantity reported.		Average value per 1,000 feet f. o. b. mill.
		M feet b. m.	Per cent.	
United States	2,583	270,407	100.0	$58.87
West Virginia	236	64,443	23.8	74.28
Tennessee	421	45,436	16.8	60.15
Virginia	329	34,738	12.8	55.15
Kentucky	294	31,462	11.6	54.26
North Carolina	220	20,584	7.6	49.61
Georgia	87	17,169	6.4	62.86
Alabama	198	16,933	6.3	39.79
Mississippi	97	10,915	4.0	45.43
Ohio	174	9,304	3.4	59.51
Indiana	166	5,875	2.2	61.40
Pennsylvania	157	4,528	1.7	49.01
South Carolina	27	3,789	1.4	42.71
Maryland	56	2,077	.8	40.24
All other States (see Table 37, p. 56)	121	3,154	1.2	39.83

[1] Yellow poplar (*Liriodendron tulipifera*) is the only species that goes into poplar lumber.

TABLE 22.—*Reported production of beech* [1] *lumber in 1920.*

[Computed total production in the United States, 325,000 M feet.]

State.	Number of active mills reporting.	Quantity reported.		Average value per 1,000 feet f. o. b. mill.
		M feet b. m.	Per cent.	
United States	3,051	264,572	100.0	$36.51
New York	700	43,982	16.6	37.59
Michigan	127	41,987	15.9	41.28
Pennsylvania	247	34,471	13.0	37.29
Indiana	314	33,471	12.7	35.83
West Virginia	196	27,826	10.5	40.92
Ohio	304	18,970	7.2	33.99
Kentucky	283	17,565	6.6	28.74
Louisiana	33	10,446	3.9	26.14
Tennessee	285	8,711	3.3	29.84
Vermont	132	6,206	2.3	36.04
New Hampshire	58	4,447	1.7	34.42
Virginia	67	4,189	1.6	47.79
Mississippi	39	2,289	.9	32.42
North Carolina	30	2,154	.8	32.26
All other States (see Table 37, p. 56)	236	7,858	3.0	31.41

[1] Beech (*Fagus atropunicea*) is the only species that goes into beech lumber.

TABLE 23.—*Reported production of white fir*[1] *lumber in 1920.*

[Computed total production in the United States, 280,000 M feet.]

State.	Number of active mills reporting	Quantity reported.		Average value per 1,000 feet f. o. b. mill.
		M feet b. m.	Per cent.	
United States	231	279,645	100.0	$30.44
California, including Nevada	65	151,957	54.3	30.05
Idaho	38	54,424	19.5	35.23
Washington	43	32,395	11.6	22.49
Montana	4	22,891	8.2	37.80
Oregon	51	14,199	5.1	23.30
All other States (see Table 37, p. 56)	30	3,779	1.3	27.38

[1] White fir (*Abies concolor*) is cut only in the West. Marketed as White fir are: Lowland white fir (*A. grandis*), cut mostly in Idaho and Montana; silver fir (*A. amabilis*), cut chiefly in Washington; red fir (*A. magnifica*), cut chiefly in California; alpine fir (*A. lasiocarpa*), cut chiefly in the northern Rocky Mountain and Cascade Mountain region.

TABLE 24.—*Reported production of cedar*[1] *lumber in 1920.*

[Computed total production in the United States, 260,000 M feet].

State	Number of active mills reporting.	Quantity reported.		Average value per 1,000 feet f. o. b. mill.
		M feet b. m.	Per cent.	
United States	637	245,079	100.0	$38.68
Washington	96	113,351	46.2	36.65
California	71	36,030	14.7	31.68
Oregon	51	34,482	14.1	47.09
Idaho	21	26,663	10.9	34.48
Tennessee	111	10,963	4.5	69.61
Maine	55	6,837	2.8	35.27
Michigan	34	5,252	2.1	33.56
Wisconsin	41	2,445	1.0	29.72
All other States (see Table 37, p. 56)	157	9,056	3.7	42.85

[1] Western red cedar (*Thuja plicata*) is cut in Washington, Oregon, and Idaho. Port Orford cedar (*Chamaecyparis lawsoniana*) is cut in Oregon. Alaska cedar (*C. nootkatensis*) is cut in Washington. Incense cedar (*Libocedrus decurrens*) is cut in California. Northern white cedar (*T. occidentalis*) is cut in the Lake States and the Northeastern States. Southern white cedar (*C. thyoides*) is cut in the Atlantic Coast States. Red cedar (*Juniperus virginiana*) and southern red juniper (*Y. barbadensis*) are cut principally in Tennessee, Florida, and Alabama.

TABLE 25.—*Reported production of elm*[1] *lumber in 1920.*

[Computed total production in the United States, 225,000 M feet.]

State.	Number of active mills reporting.	Quantity reported.		Average value per 1,000 feet f. o. b. mill.
		M feet b. m.	Per cent.	
United States	2,473	182,845	100.0	$47.23
Wisconsin	237	49,120	26.9	53.91
Michigan	164	28,951	15.8	59.07
Arkansas	117	20,938	11.4	43.24
Indiana	253	20,012	10.9	51.88
Ohio	280	10,751	5.9	43.36
Mississippi	75	9,272	5.1	44.78
Missouri	122	9,118	5.0	32.17
New York	423	6,879	3.8	40.31
Tennessee	139	6,692	3.7	31.92
Louisiana	45	5,763	3.1	27.72
Minnesota	96	4,611	2.5	28.05
All other States (see Table 37, p. 56)	522	10,738	5.9	32.14

[1] White (or soft) elm (*Ulmus americana*) is cut in all of the States east of the Rocky Mountains. Slippery (or red, or soft) elm (*U. pubescens*) is cut in the same region as white elm. Cork (or true rock) elm (*U. racemosa*) is cut in the Lake States. Wing elm (*U. alata*) and cedar elm (*U. crassifolia*) are occassionally cut in the lower Mississippi Valley.

TABLE 26.—*Reported production of basswood* [1] *lumber in 1920.*

[Computed total production in the United States, 195,000 M feet.]

State.	Number of active mills reporting.	Quantity reported.		Average value per 1,000 feet f. o. b. mill.
		M feet b. m.	Per cent.	
United States	2,372	169,276	100.0	$54.28
Wisconsin	225	59,067	34.9	57.05
Michigan	154	23,562	13.9	56.65
West Virginia	138	19,369	11.5	60.81
New York	679	14,834	8.8	50.44
North Carolina	66	7,616	4.5	44.81
Virginia	56	7,258	4.3	64.16
Minnesota	104	5,412	3.2	38.69
Tennessee	70	4,953	2.9	52.87
Ohio	165	4,940	2.9	50.14
Indiana	122	4,662	2.8	53.24
Pennsylvania	153	4,417	2.6	53.59
Vermont	127	4,308	2.5	44.88
Kentucky	99	4,303	2.5	42.36
All other States (see Table 37, p. 56)	214	4,575	2.7	37.56

[1] Basswood (or linn) (*Tilia americana*) is cut principally in the Lake States. White basswood (*T. heterophylla*) is cut in the Appalachian Mountain region. Downy basswood (*T. pubescens*) is cut in limited quantity in the Southern States.

TABLE 27.—*Reported production of tupelo* [1] *lumber in 1920.*

[Computed total production in the United States, 180,000 M feet.]

State.	Number of active mills reporting	Quantity reported.		Average value per 1,000 feet f. o. b. mill.
		M feet b. m.	Per cent.	
United States	721	161,055	100.0	$33.68
Louisiana	45	87,038	54.0	35.09
Alabama	46	12,696	7.9	36.74
South Carolina	21	12,278	7.6	38.54
Mississippi	52	8,758	5.4	27.01
Arkansas	71	7,685	4.8	31.73
Virginia	39	7,639	4.8	29.12
North Carolina	45	4,730	2.9	32.90
Tennessee	84	3,583	2.2	28.99
Missouri	25	3,430	2.1	22.52
Illinois	10	2,494	1.6	18.46
All other States (see Table 37, p. 56)	283	10,724	6.7	32.22

[1] Tupelo (or cotton gum) (*Nyssa aquatica*) is cut in the Gulf States. Black gum (or pepperidge) (*N. sylvatica*) is cut in the Atlantic and Central States and is sold both as tupelo and black gum. Water gum (*N. biflora*) is cut to a small extent in the South Atlantic States.

TABLE 28.—*Reported production of ash*[1] *lumber in 1920.*

[Computed total production in the United States, 170,000 M feet.]

State.	Number of active mills reporting.	Quantity reported.		Average value per 1,000 feet f. o. b. mill.
		M feet b. m.	Per cent.	
United States	3,161	147,618	100.0	$61.28
Louisiana	66	20,051	13.6	57.44
Arkansas	130	16,516	11.2	53.54
Wisconsin	173	12,939	8.8	56.55
Indiana	223	12,104	8.2	87.42
Tennessee	173	10,911	7.4	69.59
Ohio	284	9,948	6.7	76.28
New York	620	9,363	6.4	57.74
Mississippi	75	7,665	5.2	50.54
Michigan	126	5,816	3.9	55.59
West Virginia	109	5,063	3.4	86.96
Georgia	27	4,894	3.3	55.37
Pennsylvania	250	3,867	2.6	62.69
Alabama	42	3,696	2.4	51.69
Missouri	68	3,527	2.4	55.45
South Carolina	20	3,372	2.3	70.99
Kentucky	157	3,321	2.3	50.18
All other States (see Table 37, p. 56)	618	14,665	9.9	48.36

[1] Lumber trade practice specifies white ash and brown ash. The former is cut from the white-ash tree and the latter from the black-ash tree. White ash (*Fraxinus americana*) is cut principally in the Central States. Green ash (*F. lanceolata*) is cut principally in Southern States. Black ash (*F. nigra*) is cut in the Lake States and northeastern States. Red ash (*F. pennsylvanica*) is cut in limited quantity in the Eastern States. Oregon ash (*F. oregona*) is cut in the Pacific Northwest.

TABLE 29.—*Reported production of cottonwood*[1] *lumber in 1920.*

[Computed total production in the United States, 155,000 M feet.]

State.	Number of active mills reporting.	Quantity reported.		Average value per 1,000 feet f. o. b. mill.
		M feet b. m.	Per cent.	
United States	926	138,076	100.0	$33.38
Minnesota	99	47,773	34.6	27.38
Mississippi	55	21,798	15.8	38.51
Arkansas	47	13,673	9.9	43.08
Louisiana	34	8,165	5.9	31.19
Wisconsin	50	7,464	5.4	32.26
Missouri	57	6,133	4.4	37.37
Michigan	42	5,454	4.0	32.04
Tennessee	43	4,937	3.6	40.81
Iowa	44	3,578	2.6	35.46
Oklahoma	10	3,160	2.3	31.78
All other States (see Table 37, p. 56)	445	15,941	11.5	34.15

[1] Common cottonwood (*Populus deltoides*) is the species most commonly cut east of the Rocky Mountains and more particularly in the lower Mississippi Valley. Swamp cottonwood (*P. heterophylla*) is cut in the Mississippi Valley States. Aspen (or popple) (*P. tremuloides*) is cut in the Lake States and the Northeastern States, and to a limited extent in the Rocky Mountains and farther west. Large-toothed aspen (*P. grandidentata*) is cut in the Lake States and Northeastern States. Balm of Gilead (*P. balsamifera*) is cut in the Lake States and Eastern States. Black cottonwood (*P. trichocarpa*) is cut in the Pacific Coast States.

TABLE 30.—*Reported production of hickory* [1] *lumber in 1920.*

[Computed total production in the United States, 150,000 M feet.]

State.	Number of active mills reporting.	Quantity reported.		Average value per 1,000 feet f. o. b. mill.
		M feet b. m.	Per cent.	
United States	2,686	131,553	100.0	$52.57
Arkansas	174	28,594	21.7	58.59
Tennessee	306	21,993	16.7	48.82
Kentucky	259	11,492	8.7	48.96
West Virginia	206	11,448	8.7	49.18
Indiana	267	9,532	7.2	55.78
Mississippi	79	9,345	7.1	53.09
Ohio	309	6,818	5.2	62.48
Missouri	130	6,370	4.9	52.71
Louisiana	43	4,913	3.7	62.32
Pennsylvania	134	3,799	2.9	43.21
Virginia	179	2,982	2.3	41.11
Illinois	70	2,848	2.2	42.59
North Carolina	104	2,327	1.8	37.92
All other States (see Table 37, p. 56)	426	9,092	6.9	49.36

[1] Several species of hickory are cut, the principal ones being shagbark (*Hicoria ovata*), shellbark (*H. laciniosa*), pignut (*H. glabra*), bitternut (*H. minima*), and mockernut (*H. alba*).

TABLE 31.—*Reported production of sugar pine* [1] *lumber in 1920.*

[Computed total production in the United States, 146,000 M feet.]

State.	Number of active mills reporting.	Quantity reported.		Average value per 1,000 feet f. o. b. mill.
		M feet b. m.	Per cent.	
United States	73	145,906	100.0	$48.76
California	62	141,134	96.7	49.20
Oregon	11	4,772	3.3	35.78

[1] Sugar pine (*Pinus lambertiana*) is the only species cut as such and is found commercially only in California and southern Oregon.

TABLE 32.—*Reported production of balsam fir* [1] *lumber in 1920.*

[Computed total production in the United States, 85,000 M feet.]

State.	Number of active mills reporting.	Quantity reported.		Average value per 1,000 feet f. o. b. mill
		M feet b. m.	Per cent.	
United States	407	70,511	100.0	$34.33
Maine	142	31,042	44.0	35.39
Wisconsin	38	13,903	19.7	36.23
Minnesota	53	12,377	17.6	28.52
Michigan	39	5,321	7.5	36.83
Vermont	72	4,440	6.3	34.59
New Hampshire	29	2,332	3.3	27.87
All other States (see Table 37, p. 56)	34	1,096	1.6	46.26

[1] Balsam fir (*Abies balsamea*) is the only species cut as such.

TABLE 33.—*Reported production of walnut* [1] *lumber in 1920.*

[Computed total production in the United States, 35,000 M feet.]

State.	Number of active mills reporting.	Quantity reported.		Average value per 1,000 feet f. o. b. mill.
		M feet b. m.	Per cent.	
United States	1,076	32,704	100.0	$88.92
Missouri	69	6,962	21.3	64.18
Ohio	150	5,589	17.1	100.72
Indiana	165	4,723	14.4	94.77
Illinois	28	2,445	7.5	102.14
Kentucky	137	2,186	6.7	83.91
Iowa	21	2,112	6.5	59.82
Tennessee	104	1,392	4.2	77.98
West Virginia	88	1,008	3.1	58.59
All other States (see Table 37, p. 56)	314	6,287	19.2	115.09

[1] Black walnut (*Juglans nigra*) is the only species cut as such.

TABLE 34.—*Reported production of lodgepole pine* [1] *lumber in 1920.*

[Computed total production in the United States, 31,000 M feet.]

State.	Number of active mills reporting.	Quantity reported.		Average value per 1,000 feet f. o. b. mill.
		M feet b. m.	Per cent.	
United States	103	30,136	100.0	$30.58
Montana	19	15,603	51.8	33.03
Colorado	39	10,634	35.3	29.45
Wyoming	24	2,744	9.1	23.50
All other States (see Table 37, p. 56)	21	1,155	3.8	24.71

[1] Lodgepole pine (*Pinus contorta*) is the only species cut as such.

TABLE 35.—*Reported production of sycamore* [1] *lumber in 1920.*

[Computed total production in the United States, 31,000 M feet.]

State.	Number of active mills reporting.	Quantity reported.		Average value per 1,000 feet f. o. b. mill.
		M feet b. m.	Per cent.	
United States	915	29,256	100.0	$32.12
Arkansas	64	6,966	23.8	36.62
Indiana	188	4,106	14.0	34.54
Mississippi	35	3,519	12.0	31.79
Missouri	98	2,667	9.1	28.56
Tennessee	46	1,991	6.8	31.13
Kentucky	120	1,915	6.6	27.89
Ohio	108	1,741	6.0	35.38
North Carolina	3	1,527	5.2	29.90
Illinois	46	1,178	4.0	24.73
All other States (see Table 37, p. 56)	207	3,646	12.5	28.22

[1] Sycamore (*Platanus occidentalis*) is the only species cut as such.

TABLE 36.—*Reported production of minor species in 1920.*

[Computed total production in the United States, 68,300 M feet.]

Kind of wood.	Number of active mills reporting.	Quantity reported, M feet b. m.	Average value per 1,000 feet f. o. b. mill.	States reporting
Total		64,158	$100.89	
Mahogany	9	21,193	211.47	Louisiana, New York, Indiana, Illinois, Ohio.
Cherry	220	8,563	76.48	West Virginia, New York, Pennsylvania, Ohio, Indiana, Tennessee, North Carolina, Michigan, Virginia, Kentucky, Vermont, Massachusetts, Arkansas, Illinois, Wisconsin, Connecticut, Maryland.
Willow	15	7,480	32.18	Louisiana, Mississippi, Arkansas, New York, Wisconsin, Virginia.
Noble fir	(1)	6,397	33.53	Oregon.
Pecan	51	3,990	38.17	Louisiana, Arkansas, Mississippi, Oklahoma, Tennessee, Illinois, Texas.
Buckeye	59	3,980	46.25	Tennessee, North Carolina, Virginia, West Virginia, Kentucky, Ohio.
Magnolia	31	3,879	36.00	Louisiana, Mississippi, Texas, Georgia, Alabama.
Hackberry	57	1,974	29.69	Arkansas, Mississippi, Louisiana, Indiana, Illinois, Oklahoma, Missouri, Alabama, Tennessee, Ohio.
Locust	52	1,700	36.14	Pennsylvania, Indiana, Arkansas, Louisiana, Maryland, West Virginia, Missouri, Mississippi, Tennessee, Virginia, Ohio, Kentucky, North Carolina, Illinois.
Alder	14	1,624	38.40	Washington, Oregon.
Butternut	63	654	46.55	West Virginia, Wisconsin, Indiana, New York, Virginia, Vermont, North Carolina, Minnesota, Pennsylvania, Tennessee, Ohio, Michigan, Kentucky.
Cucumber	19	616	49.09	West Virginia, Pennsylvania, New York, Ohio, Tennessee.
Dogwood	(1)	603	75.00	Florida, Mississippi.
Laurel	(1)	500	60.00	California.
Persimmon	16	399	85.49	Arkansas, South Carolina, Florida, Mississippi, Georgia, Missouri, Louisiana.
Spanish cedar	3	234	140.92	New York, Louisiana, Ohio.
Bellwood	(1)	117	54.46	Tennessee.
Red bay	3	93	46.09	Georgia, Alabama, South Carolina.
Apple	(1)	72	40.00	New York, Indiana.
Holly	(1)	31	111.13	Massachusetts, Mississippi.
Sassafras	8	15	41.33	Arkansas, Tennessee, Indiana.
Chittam	(1)	15	34.67	North Carolina, Tennessee.
Box elder	(1)	14	31.28	North Carolina.
Boxwood	(1)	13	[2] 100.00	Illinois.
Coffee tree	(1)	1	[2] 30.00	Arkansas.
Mulberry	(1)	1	[2] 30.00	Ohio.

[1] Less than 3 mills. [2] Arbitrary value assigned.

LUMBER PRODUCTION BY STATES AND SPECIES.

Table 37 is a recapitulation for the United States of the 1920 lumber production figures shown in Tables 7 to 36, inclusive. The aggregate reported production of softwoods and hardwoods in each State is shown, and also the production of lath and shingles.

TABLE 37.—*Reported production of lumber, by States and species, and of lath and shingles, in 1920.*

State	Number of active saw mills reporting.	Aggregate softwoods and hardwoods.	Softwoods.															
			Total softwoods.	Yellow pine.	Douglas fir.	Western yellow pine.	Hemlock.	White pine.	Spruce.	Cypress.	Redwood.	Larch.	White fir.	Cedar.	Sugar pine.	Balsam fir.	Lodgepole pine.
		M feet b. m.	*M feet b. m.*	*M feet b. m.*	*M feet b. m.*	*M feet b. m.*	*M feet b. m.*	*M feet b. m.*	*M feet b. m.*	*M feet b. m.*	*M feet b. m.*	*M feet b. m.*	*M feet b. m.*	*M feet b. m.*	*M feet b. m.*	*M feet b. m.*	*M feet b. m.*
United States	15,978	29,878,360	24,253,918	8,964,313	6,956,683	2,270,898	1,685,320	1,377,327	805,320	571,674	476,003	375,103	279,645	245,079	145,906	70,511	30,136
Alabama	903	1,108,188	988,973	985,773						2,893				307			
Arizona	20	120,495	120,494		1,086	119,406							2				
Arkansas	656	1,148,158	621,159	586,369						34,790							
California and Nevada	195	1,482,102	1,481,577		161,632	509,471	50		5,300		476,003		151,957	36,030	141,134		
Colorado	151	67,847	67,836		2,615	37,191			13,859				3,457	80			10,634
Connecticut	122	44,996	6,451	54			1,980	4,383						34			
Delaware	34	11,990	9,888	9,878										10			
Florida	204	863,013	849,702	744,373						105,329							
Georgia	713	599,739	527,100	478,547			425	2,253		45,863				12			
Idaho	188	969,576	968,198		105,786	366,857	120	261,251	10,572			142,103	54,424	26,663			422
Illinois	129	44,469	1,957	35						1,922							
Indiana	404	210,045	223	1										222			
Iowa	53	12,617	20					20									
Kansas ans Nebraska	5	4,245															
Kentucky	558	270,882	22,331	8,895			6,775	2,498		2,340				1,823			
Louisiana	271	2,719,761	2,339,379	2,066,263						273,116							
Maine	441	450,196	422,595	175			54,726	165,102	164,652			61		6,837		31,042	
Maryland	221	65,202	36,125	35,360			650	63		20				32			
Massachusetts	191	100,266	68,887	120			7,105	57,905	3,436			120		186		15	
Michigan	243	726,147	274,742				206,840	36,186	8,686			12,457		5,252		5,321	
Minnesota	246	556,265	485,315				183	429,210	31,492			11,706		347		12,377	
Mississippi	648	1,677,469	1,334,904	1,322,958						11,945				1			
Missouri	405	231,361	64,899	23,693						41,053				153			
Montana	124	409,667	408,551		55,670	173,507		5,061	21,573			112,400	22,891	1,846			15,603
New Hampshire	223	223,376	190,887				23,508	121,202	43,835			10				2,332	
New Jersey	74	16,466	6,372	5,419			178	55						720			
New Mexico	60	109,882	109,881		5,731	104,059							90	1			
New York	1,206	410,909	169,909	248			74,004	66,311	27,823			262		305		996	
North Carolina	1,215	786,412	595,689	517,425			33,271	4,180	33,588	5,913				1,312			
Ohio	473	185,881	505	125			362	18									

Oklahoma	78	154,598	135,488	135,280						208							
Oregon	659	3,316,098	3,306,463		2,347,368	630,326	89,130	2,830	165,418			17,938	14,199	34,482	4,772		
Pennsylvania	832	401,660	165,790	1,690			134,740	29,004	193					38		125	
Rhode Island	19	7,489	1,946				53	1,768						125			
South Carolina	368	520,210	472,447	436,246						36,183				18			
South Dakota	44	45,033	45,033			45,033											
Tennessee	609	554,991	127,468	74,167			32,721	3,880		5,737				10,963			
Texas	232	1,177,436	1,126,145	1,125,015						1,130							
Utah	58	7,591	7,540		427	4,135			2,087				158				733
Vermont	265	114,601	61,788				17,330	13,827	25,962			15		214		4,440	
Virginia	1,065	735,729	432,425	404,804			16,992	6,127		3,232				1,270			
Washington	584	5,524,509	5,522,768		4,275,017	278,573	495,444	69,051	192,671			66,266	32,395	113,351			
West Virginia	398	647,055	141,092	1,400			85,408	6,163	48,121								
Wisconsin	350	1,036,550	525,790				403,325	88,979	5,373			11,765		2,445		13,903	
Wyoming	41	7,188	7,186		1,351	2,340			679				72				2,744

TABLE 37.—*Reported production of lumber, by States and species, and of lath and shingles, in 1920*—Continued.

State.	Hardwoods.																	Lath.	Shingles.
	Total hardwoods.	Oak.	Maple.	Gum, red and sap.	Chestnut.	Birch.	Yellow poplar.	Beech.	Elm.	Basswood.	Tupelo.	Ash.	Cottonwood.	Hickory.	Walnut.	Sycamore.	Minor species.		
	M feet b. m.	*M feet b. m.*	*M feet b. m.*	*M feet b. m.*	*M feet b. m.*	*M feet b. m.*	*M feet b. m.*	*M feet b. m.*	*M feet b. m.*	*M feet b. m.*	*M feet b. m.*	*M feet b. m.*	*M feet b. m.*	*M feet b. m.*	*M feet b. m.*	*M feet b. m.*	*M feet b. m.*	*Thousands.*	*Thousands.*
United States	5,624,442	1,853,580	768,345	684,745	379,675	346,577	270,407	264,572	182,845	169,276	161,055	147,618	138,076	131,553	32,704	29,256	64,158	1,952,983	6,156,416
Alabama	119,215	46,646	102	33,700	960	9	16,933	483	356	19	12,696	3,596	1,430	1,852	39	341	53	32,444	32,615
Arizona	1	1																18,453	
Arkansas	526,999	225,422	6,890	194,981		127	328	1,251	20,938	90	7,685	16,516	13,673	28,594	188	6,966	3,350	50,108	19,770
California and Nevada	525	25															500	36,793	167,130
Colorado	11	1											10					3,279	
Connecticut	38,545	10,257	1,350		22,875	1,037	441	304	214	327		554	116	810	248		12	200	103
Delaware	2,102	1,602	106	338	9		15	1			10	5		15		1		950	4
Florida	13,311	60		7,255			151				1,983	1,498	550	1,214			600	89,948	67,689
Georgia	72,639	26,003	303	17,991	2,561	20	7,169	104	270	50	1,518	4,894	133	960	3	541	119	39,840	59,058
Idaho	1,378												1,378					97,182	25,211
Illinois	42,512	23,377	2,181	2,946	28	42	611	171	2,356	59	2,494	668	558	2,848	2,445	1,178	550	35	
Indiana	209,822	79,640	26,664	4,231	505	276	15,875	33,471	20,012	4,662	1,229	12,104	1,181	9,532	4,723	4,106	1,611	450	100
Iowa	12,597	3,174	466			107			1,760	947		310	3,578	119	2,112	24		26	
Kansas and Nebraska	4,245												370		3,875				
Kentucky	248,551	141,588	6,268	7,417	16,011	559	31,462	17,565	1,363	4,303	1,553	3,321	1,311	11,492	2,186	1,915	237	2,752	910
Louisiana	380,382	92,725	154	125,944		8	491	10,446	5,763	229	87,038	20,051	8,165	4,913	5	725	23,725	215,738	211,503
Maine	27,601	3,283	3,465			17,496		1,529	165	867		498	298					101,704	140,038
Maryland	29,077	16,906	692	2,464	5,342	135	2,077	323	17	166	8	57	30	373	24	418	45	579	282
Massachusetts	31,379	5,380	3,143		17,682	1,939	134	1,496	114	303	50	834	78	95	83		48	184	708
Michigan	451,405	5,457	279,911		14	58,866	409	41,987	28,951	23,562		5,816	5,454	683	97	111	87	50,892	116,678
Minnesota	70,950	5,274	545			6,427		10	4,611	5,412		830	47,773	1	42		25	117,300	1,678
Mississippi	342,565	115,399	1,188	147,781		133	10,915	2,289	9,272	603	8,758	7,665	21,798	9,345	3	3,519	3,897	113,707	22,858
Missouri	166,462	101,667	8,679	17,304		116	128	152	9,118	147	3,430	3,527	6,133	6,370	6,962	2,667	62	3,737	603
Montana	1,116												1,116					47,673	6,243
New Hampshire	32,489	5,974	7,702		2,070	10,023		4,447	113	653		607	820		80			10,642	1,452
New Jersey	10,094	4,838	277	181	3,764	74	372	102	109	5	36	95		230	10	1		3,838	5,827
New Mexico	1	1																19,783	10
New York	241,000	32,157	72,724		17,780	33,221	43	43,982	6,879	14,834		9,363	784	1,068	47	14	8,104	13,484	5,630
North Carolina	190,723	82,671	5,791	8,687	47,170	2,423	20,584	2,154	75	7,616	4,730	2,741	347	2,327	288	1,527	1,592	14,182	47,403
Ohio	185,376	85,131	21,817	605	7,227	335	9,304	18,970	10,751	4,940	446	9,948	737	6,818	5,589	1,741	1,017	1,361	225

Oklahoma	19,110	7,212	62	6,546	.....	.....	.....	1	692	78	.....	504	3,160	294	7	467	87	14,173	410
Oregon	9,635	126	1,021	.....	.....	.....	.....	.....	.....	.....	.....	625	1,035	.....	.....	.....	6,828	173,732	288,721
Pennsylvania	235,870	88,729	39,194	905	45,067	6,370	4,528	34,471	1,300	4,417	235	3,867	356	3,799	504	65	2,063	13,084	3,486
Rhode Island	5,543	1,800	310	.....	3,135	64	31	30	10	.....	.....	100	.....	43	20	.....	.....	.....	20
South Carolina	47,763	5,679	1,284	20,483	.....	.....	3,789	.....	305	.....	12,278	3,372	254	43	1	164	111	9,278	5,031
South Dakota	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	9,362	108
Tennessee	427,523	221,260	6,736	52,821	32,653	1,494	45,436	8,711	6,692	4,953	3,583	10,911	4,937	21,993	1,392	1,991	1,960	5,473	3,513
Texas	51,291	27,074	.....	18,033	.....	.....	.....	225	167	32	1,307	1,279	1,588	1,204	39	36	307	48,766	3,798
Utah	51	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	51	.....	.....	.....	.....	382	425
Vermont	52,813	3,152	17,759	.....	1,418	15,307	.....	6,206	794	4,308	372	2,501	860	56	15	.....	65	1,188	3,524
Virginia	303,304	166,667	6,391	12,607	56,103	1,754	34,738	4,189	31	7,258	7,639	959	197	2,982	635	347	807	27,548	1,940
Washington	1,741	.....	288	.....	.....	.....	.....	.....	.....	.....	.....	.....	260	.....	.....	.....	1,193	404,942	4,847,105
West Virginia	505,963	202,499	56,630	1,525	97,301	10,910	64,443	27,826	527	19,369	1,977	5,063	91	11,448	1,008	391	4,955	33,543	128
Wisconsin	510,760	14,723	188,252	.....	.....	177,305	.....	1,676	49,120	59,067	.....	12,939	7,464	32	34	.....	148	124,198	479
Wyoming	2	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	2	.....	.....	.....	.....	50	.....

LUMBER VALUES.

The average values for lumber shown in Table 38 were determined for each species from the individual reports of mills, representing every variation incident to the size of mill, region, logging conditions, transportation, manufacture, and sale of lumber The values given in the tables are weighted by the quantities produced at both large mills and small mills and accurately reflect the average value of the several species of lumber at the average mill. The variation in values for the same wood in different States is largely caused by differences in the quality of timber, perfection of manufacture, and quantity produced by the mill.

Average mill values reported by associations or by exclusively large mills are usually larger than those in Table 38, probably for the reason that the larger organizations are in a position to sell to better advantage than the owners of small mills.

The average value of $38.42 per thousand for all lumber sawed in 1920 is an increase of $8.21 or 27 per cent above the 1919 valuation. This is the highest value, and the greatest increase in value per year, for which statistics are available. All species shared in the advance.

For valuations of the total cut, the cut of each State, and the cut of geographic groups, refer to Table 4A, page 34. The value of the 1920 cut exceeded that of 1919 by $255,000,000. In the consideration of all lumber values at the present period the decreased purchasing power of the dollar should be kept in mind. The lumber cut of 1899, which was only about a billion feet greater than that of 1920, was valued at $385,300,000, while the cut of 1920 is valued at $1,298,900,000. The increase in valuation for approximately the same quantity is 237 per cent.

TABLE 38.—*Average value f. o. b. mill per 1,000 feet board measure, by kinds of wood, for specified years, 1909–1920.*

Kind of wood.	1920	1919	1918	1917	1916	1915	1911	1910	1909
All kinds	$38.42	$30.21	$24.79	$20.32	$15.32	$14.04	$15.05	$15.30	$15.38
Softwoods:									
Yellow pine	35.89	28.71	24.38	19.00	14.33	12.41	13.87	13.29	12.69
Douglas fir	34.59	24.62	18.77	16.28	10.78	10.59	11.05	13.09	12.44
Western yellow pine	38.73	27.75	20.87	19.59	14.52	14.32	13.62	14.25	15.39
Hemlock	32.05	29.16	23.97	20.78	15.35	13.14	13.59	13.85	13.95
White pine	41.49	32.83	30.84	24.81	19.16	17.44	18.54	18.93	18.16
Spruce	38.94	30.76	28.65	24.41	17.58	16.58	16.14	16.62	16.91
Cypress	51.02	38.38	30.56	23.92	20.85	19.85	20.54	20.51	20.46
Redwood	46.90	30.04	24.30	21.00	13.93	13.54	13.99	15.52	14.80
Larch (tamarack)	30.28	23.39	19.86	16.21	12.49	10.78	11.87	12.33	12.68
White fir	30.44	25.66	19.61	17.16	12.25	10.94	10.64	11.52	13.10
Cedar	38.68	33.80	24.86	19.40	15.24	16.10	13.86	15.53	19.95
Sugar pine	48.76	35.99	28.26	24.69	16.77	17.40	17.52	18.68	18.14
Balsam fir	34.33	32.23	27.27	20.02	16.49	13.79	13.42	14.48	13.99
Lodgepole pine	30.58	29.98	20.95	18.34	15.13	13.57	12.41	14.88	16.25
Hardwoods:									
Oak	46.88	37.87	31.11	24.49	20.06	18.73	19.14	18.76	20.50
Maple	50.16	35.56	29.05	23.16	18.24	15.21	15.49	18.16	15.77
Gum, red and sap	35.24	32.68	23.21	19.56	14.64	12.54	12.11	12.26	13.20
Chestnut	42.48	32.30	27.31	21.54	17.05	16.17	16.63	16.23	16.12
Birch	53.44	35.79	29.94	24.07	19.59	16.52	16.61	17.37	16.95
Yellow poplar	58.87	41.65	35.06	27.17	21.89	22.45	25.46	24.71	25.39
Beech	36.51	29.97	25.06	19.58	16.20	14.01	14.09	14.34	13.25
Elm	47.23	36.39	28.19	22.89	19.46	16.98	17.13	18.67	17.52
Basswood	54.28	40.03	34.00	25.96	21.05	18.89	19.20	20.94	19.50
Tupelo	33.68	28.42	22.73	18.06	13.00	12.25	12.46	12.14	11.87
Ash	61.28	52.69	38.70	30.01	23.85	22.15	21.21	22.47	24.44
Cottonwood	33.38	32.24	26.13	23.19	17.42	17.36	18.12	17.78	18.05
Hickory	52.57	44.37	37.95	29.48	23.84	23.35	22.47	26.55	30.80
Walnut	88.92	72.13	77.60	72.99	42.38	48.37	31.70	34.91	43.79
Sycamore	32.12	30.42	23.59	18.68	14.65	13.86	13.16	14.10	14.87

LATH PRODUCTION, BY STATES.

Washington outstripped Louisiana in the production of lath for 1919, and in 1920 increased its lead. The output in the latter year was 21 per cent of the total production. Oregon also moved up from fourth to third place, and is increasing, while Louisiana has decreased in production for six years.

TABLE 39.—*Reported production of lath, 1917–1920.*

State.	Number of active mills reporting.				Quantity reported (thousands of pieces).			
	1920	1919	1918	1917	1920	1919	1918	1917
United States	1,290	1,133	909	1,456	1,952,983	1,724,078	1,362,187	2,281,738
Washington	69	72	42	58	404,942	339,058	154,668	230,194
Louisiana	51	59	53	68	215,738	199,018	236,543	348,806
Oregon	41	37	23	32	173,732	122,848	78,780	132,418
Wisconsin	101	82	75	113	124,198	138,936	122,858	185,074
Minnesota	42	44	31	45	117,300	115,741	155,905	213,092
Mississippi	28	28	27	33	113,707	96,204	81,598	133,925
Maine	82	71	50	106	101,704	104,223	62,671	142,488
Idaho	24	23	20	22	97,182	69,150	70,494	86,264
Florida	36	34	22	27	89,948	76,402	55,171	97,954
Michigan	44	53	42	62	50,892	51,469	48,533	84,352
Arkansas	28	25	30	31	50,108	72,827	26,481	147,578
Texas	15	10	11	18	48,766	35,916	21,866	47,654
Montana	20	11	11	16	47,673	21,362	21,903	23,332
Georgia	24	13	12	25	39,840	19,718	19,083	46,889
California	20	18	10	20	36,793	53,042	22,281	37,651
West Virginia	41	37	29	54	33,543	22,005	33,289	44,233
Alabama	24	24	18	31	32,444	42,502	25,227	39,685
Virginia	62	46	50	71	27,548	27,073	16,902	30,244
All other States (see Summary, p. —)	538	446	353	624	146,925	116,584	107,934	209,905

SHINGLE PRODUCTION, BY STATES.

Shingle production has decreased about 60 per cent since 1905, owing largely to the introduction of other forms of roofing. Washington and Oregon have for many years held the lead in shingle production, and together in 1920 manufactured 83 per cent of the total output. (Fig. 16.)

TABLE 40.—*Reported production of shingles, 1917–1920.*

State.	Number of active mills reporting.				Quantity reported (thousands of pieces).			
	1920	1919	1918	1917	1920	1919	1918	1917
United States	1,133	1,726	1,052	1,619	6,156,416	9,192,704	5,690,182	8,696,513
Washington	206	292	158	230	4,847,105	7,095,122	4,238,714	6,313,364
Oregon	21	53	25	42	288,721	530,066	281,138	481,353
Louisiana	34	52	44	55	211,503	300,784	272,866	453,819
California	38	40	20	41	167,130	191,83[illegible]	146,071	261,434
Maine	137	182	100	150	140,038	188,576	87,193	166,101
Michigan	40	63	48	69	116,678	144,173	148,565	203,907
Florida	32	71	37	49	67,689	128,286	102,725	143,792
Wisconsin	45	58	63	73	64,479	96,928	91,907	151,726
Georgia	81	142	37	116	59,058	114,806	46,395	112,430
North Carolina	45	74	66	110	47,403	92,139	48,080	73,703
Alabama	70	124	60	94	32,615	62,241	50,065	54,735
Idaho	6	3	4	7	25,211	22,657	32,893	52,631
Mississippi	17	28	16	32	22,858	34,002	18,431	39,261
Arkansas	29	63	35	44	19,770	98,937	25,870	59,927
All other States (see Summary, p. —)	332	481	339	507	46,158	92,156	99,269	128,330

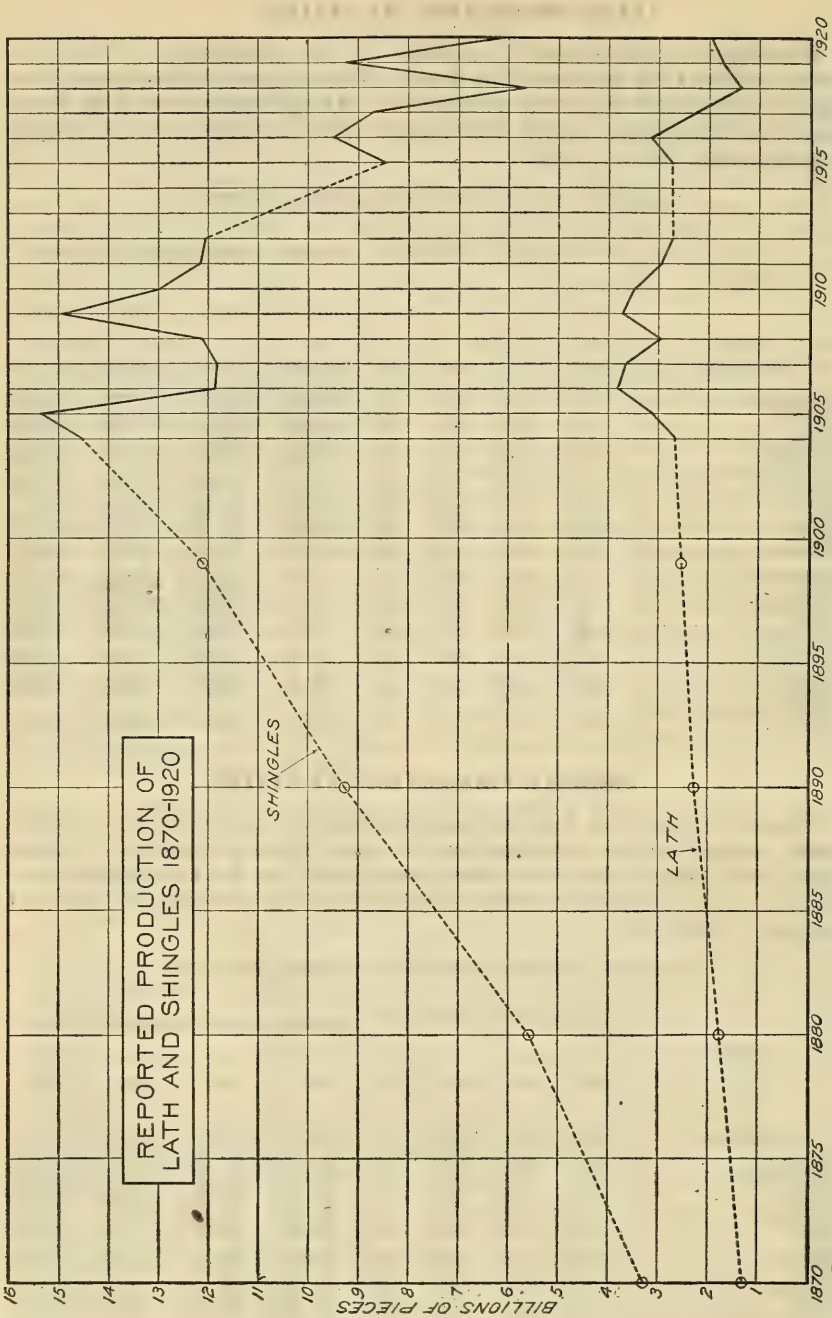


FIG. 16.—The production of wooden shingles has definitely passed its peak, probably as the result of the introduction of other forms of roofing material.

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INVESTIGATIONS OF HEAT CANKER OF FLAX.[1]

By C. S. Reddy and W. E. Brentzel, *Assistant Pathologists, Office of Cereal Investigations, Bureau of Plant Industry.*

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INTRODUCTION.

The seed-flax area of the United States coincides closely with the spring-wheat region of the Northwest, composed for the most part of the States of Minnesota, the Dakotas, and Montana. Within this area flax wilt, drought, and weeds are the most important limiting factors in flax production. Flax wilt has gradually pushed the center of flax production westward into uninfested areas, while the newly broken prairie sod with its absence of weeds has led it in the same direction. When the production of flax reached this semiarid section, complaints came from the growers that the plants often broke over at or near the surface of the soil, as though whipped off by the winds or gnawed by insects.

Fortunately for flax production, Prof. H. L. Bolley early became its advocate in North Dakota and devoted the greater part of his time to it for a number of years. He found the cause of flax wilt and developed control measures in the form of seed selection, seed treatment, and the development of resistant varieties (*1*, *2*, *3*, and *4*).[2] This has helped to eliminate losses from diseases caused by parasitic seed-borne organisms. Further work (*4* and *5*) explained the cause of one type of flax canker. As this disease was very destructive in

[1] The investigations here reported have been conducted in cooperation with the department of plant pathology of the North Dakota Agricultural Experiment Station. The writers wish to acknowledge their indebtedness to Prof. H. L. Bolley for many helpful suggestions in the progress of the work and to Dr. A. G. Johnson for assistance in the preparation of the manuscript.

[2] The serial numbers (italic) in parentheses refer to "Literature cited" at the end of this bulletin.

western North Dakota and eastern Montana, arrangements were made with the United States Department of Agriculture to continue the flax-canker investigations as a cooperative project. This paper deals with the results obtained under this cooperation, which began in 1916.

Flax canker is a term which has been applied to any injury to flax which causes it to break over at or near the soil line. However, the symptoms are not always identical in different districts or in different years. Explanations of all these symptoms have not been obtained.

ANTHRACNOSE CANKER.

Anthracnose canker was described by Bolley in 1910 (*4* and *5*), when he assigned *Colletotrichum lini* as the cause. Schoevers, in Holland (*19*), dealt with the same disease and fungus in 1915. Pethybridge and Lafferty (*15* and *16*) identified this disease in Ireland, and in 1918 they named the causative organism *Colletotrichum linicolum*. They stated that the priority of *Colletotrichum lini* Bolley was not recognized because of inadequate description. T. Hemmi in 1920 (*9*) described this disease in Japan and stated that a species of Colletotrichum was isolated which when used to inoculate young plants produced a seedling blight with typical anthracnose lesions.

In 1916 a species of Colletotrichum was isolated from flax seed of a number of varieties grown at Mandan, N. Dak., in 1915. In inoculation experiments it proved to be parasitic on flax seedlings and produced what properly could be called a damping-off seedling disease (Pl. I).

Surveys of the seed-flax area, extending over a period of six years, gave evidence that different types of flax canker are widespread and capable of producing economic loss and in isolated cases are capable of destroying whole fields of flax. Strange to say, during these six years anthracnose canker was not found by the writers in the seed-flax area, with one exception, when it was discovered on young flax about an inch and a half high at Grassrange, Mont., in 1917.

At the request of the flax-fiber specialist in the Office of Fiber-Plant Investigations a disease survey of the fiber-flax districts of Michigan and Wisconsin was made during the summer of 1920. Anthracnose canker was found to be widespread in the Michigan district. In a number of cases flax beyond the seedling stage was affected. In some instances as many as 60 per cent of the plants showed girdling, with anthracnose lesions in connection with the girdled areas. This condition closely resembled what Bolley described in 1910 and 1912 (*4* and *5*). The indications are that it is probably a combination of injuries caused by heat and parasitic fungi. The area affected may be determined more by temperature and the resulting physiological effect on the cells than by moisture, oxygen,

or light relations; but under the Michigan conditions few of the plants toppled over, and in the moist latter half of the season there was almost complete recovery. Anthracnose canker seems to be rather rare in the United States during some years, and when present its damage is confined almost entirely to young seedlings.

HEAT CANKER OF FLAX, A NONPARASITIC TYPE.

This type of flax canker, according to continuous studies since 1916 reported by the writers in 1920 (*18*), causes severe losses and occurs to about the same extent each year in the semiarid flax-producing section of the United States. It is most evident during the latter half of June and the first half of July. The outside portion of the stem is killed at or near the surface of the ground when the plants are comparatively young (Pl. II, A and B; Pl. III, A and B).

Generally speaking, if the injury occurs when the plants are less than 3 inches in height the tissues collapse at the point of injury and the plants wither and die (Pl. III, A and B; Pl. IV, A to D). If the injury occurs somewhat later, when the plants are 3 to 5 inches in height, only the cortex is killed, allowing the plants to topple over, but usually to remain alive for days or weeks because of the uninjured vascular systems within (Pl. II, A and B; Pl. V, A to C). Only in rare instances are plants more than 5 inches in height injured in this way. Numerous more mature specimens of heat-cankered flax can be found, but in such cases growth continues after the initial injury. Enlargement of the stem occurs just above and sometimes just below the injury (Pl. II, A and B; Pl. V, A to C). In most cankered plants the stem is severed, sooner or later, at the point of girdling by the winds or by the disintegration of the remaining tissues, due to the action of saprophytic organisms. Otherwise the plant dies when the starving roots can no longer support the increasing needs of the aerial portion. For this type of canker the name "heat canker of flax" is suggested.

In order to avoid confusion, it may be well to state here that the nonparasitic flax canker discussed in this paper does not include a type which occurs late in the season in the driest districts of the northern Great Plains area. Following drought the base of the stem becomes very woody, dry, and brittle, with little tensile strength, and is snapped off by the wind. This trouble also seems to be nonparasitic in its nature.

CAUSE OF HEAT CANKER.

ISOLATIONS AND PATHOGENICITY EXPERIMENTS.

Hundreds of isolations from cankered specimens of this type resulted sometimes in the growth of no organisms at all and never in the constant association of any one organism with the disease.

Numerous inoculations with fungi and bacteria from these isolations always failed to produce symptoms identical with those of the type of flax canker under consideration. Hence, this preliminary work indicated more and more clearly that this type of flax-canker injury was due to causes of a nonparasitic nature.

FIELD OBSERVATIONS.

A number of observations had tended to indicate that excessive heat at the soil line during the seedling stage possibly was the cause of the trouble. For a number of years it had been noticed at Mandan, N. Dak., that flax cankered more in the nursery plats than in the rotation plats. In the former the rows were spaced rather widely, flax was sown rather thinly, and the plats were kept free from weeds. In the rotation plats the rows were closer together, the flax was sown more thickly, and weeds were allowed to grow. As a result of these two sets of conditions, the soil was much more exposed to the intense sunlight in the nursery plats than in the rotation plats. Indications pointed, therefore, to intense sunlight as being the most important factor in causing canker. Furthermore, for a considerable time it had been noted that flax canker had been most severe in flax on breaking (freshly turned sod), where weeds are practically absent and a thin stand usually occurs. By contrast, flax fields on old land usually are weedy. This canker, therefore, developed both in the nursery and in fields under similar conditions; that is, the most canker occurred where conditions made it possible for the intense sunlight to strike the bases of the young flax plants with the least interference from weeds and other flax plants. Likewise, in a series of experimental plats at Fargo, N. Dak., in 1917, in which the stand varied greatly because of variation in germination of seed, it was noted that the most flax canker resulted where the stand was thinnest. The results of these three sets of observations are summarized in Table 1.

TABLE 1.—*Summary of field observations of heat canker of flax on plats and under field conditions in 1917.*

Location and field condition.	Canker under different conditions.	
	Thin stand; no weeds.	Thick stand; weedy.
Mandan, N. Dak.:		
Nursery plats	Canker abundant	
Rotation plats		Canker slight or absent.
Farms:		
Breaking (thin stand; few weeds)	Canker abundant	
Old land (thick stand; many weeds)		Do.
Fargo plats:		
Thin stand	Canker abundant	
Thick stand		Do.

These observations show that flax canker occurred most abundantly where the bases of the young flax plants and the adjoining soil were exposed to intense sunlight, on account of the thin stand and the absence of weeds.

ANTHRACNOSE CANKER OF FLAX SEEDLINGS 33 DAYS OLD, RESULTING FROM ARTIFICIAL INOCULATIONS.

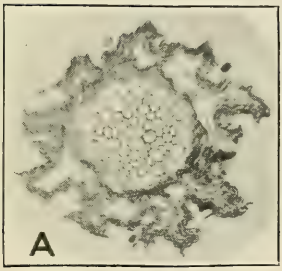
A healthy plant is shown at the right.

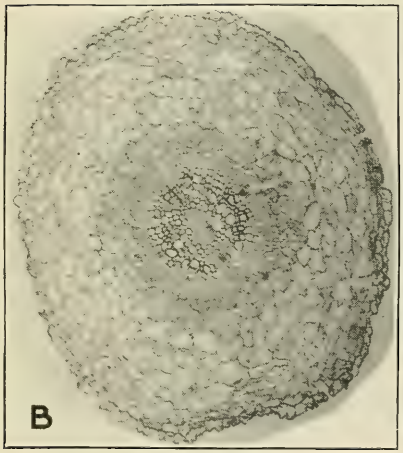
HEAT CANKER OF FLAX FROM THE FLAX NURSERY AT MANDAN, N. DAK., ON JULY 1, 1919.

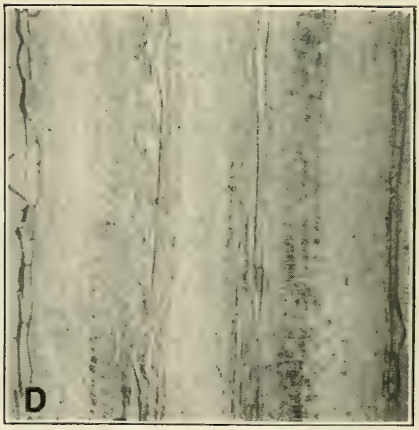
A shows a healthy plant at the right. *B* shows the tendency of cankered plants to regain an upright position after falling over. A healthy plant is shown at the right.

HEAT-CANKERED FLAX PLANTS FROM NURSERY G.

A, plants 10 days old broken over at the soil line, as seen from above. Photographed on June 18, 1920. *B*, three of the plants shown in *A*. Note the injury and discoloration of the stem at the ground line.

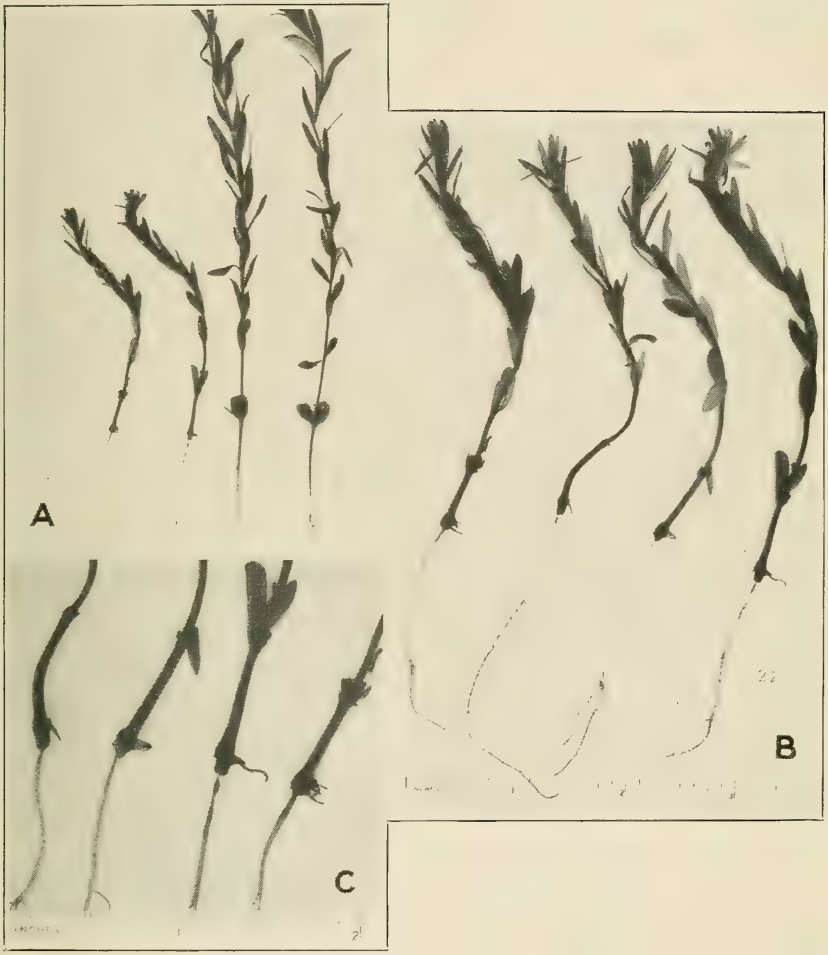






PHOTOMICROGRAPHS OF CROSS AND LONGITUDINAL SECTIONS OF STEMS OF HEAT-CANKERED FLAX PLANTS OF THE SAME AGE AS THOSE SHOWN IN PLATE III.

A, injured, constricted area of plant. This cross section shows the entire cortex destroyed. The cortical cells are broken down, but the stelar tissues are still functioning. There is no evidence of fungous mycelium in the injured tissues. Compare this with *B*. *B*, cross section immediately above the cankered area. All tissues appear healthy. Compare this with *A*. *C*, longitudinal section through the upper portion of an injured, constricted area. This shows the cortex destroyed in the cankered area. *D* longitudinal section of a young flax stem immediately above the heat-cankered area.



PLANTS FROM CANKER NURSERY G.

A, heat-cankered plants on the left; those on the right are not cankered. All four plants are of the same age. *B*, cankered plants as in *A*. *C*, the same plants as in *B*, enlarged to show the detail of the constricted areas and the enlargements just above these areas. Adventitious roots are starting at the soil line, on account of contact with moist soil. This does not occur when the soil is dry.

FIELD EXPERIMENTS.

During the latter part of the season of 1917 a shading experiment was conducted. The shade was provided by two pieces of canvas, each about 6 feet square, stretched horizontally about 3 feet from the ground above the young flax plants. In this experiment canker occurred in neither the shaded nor the unshaded area. However, the experiment did show that methods of shading which would reduce the light to a less degree were desirable. These investigations were temporarily discontinued during 1918.

In 1919 further experiments were planned and conducted to test the effect on young flax plants of intense sunlight and resulting heat at the soil line. Experiments were conducted also with a view to producing flax canker by artificial means.

Shading experiments were planned in which partial shade was provided by (1) strips of canvas, (2) cereal nurse crops, and (3) weeds. In these shading experiments the typical plat (Fig. 1) was 2

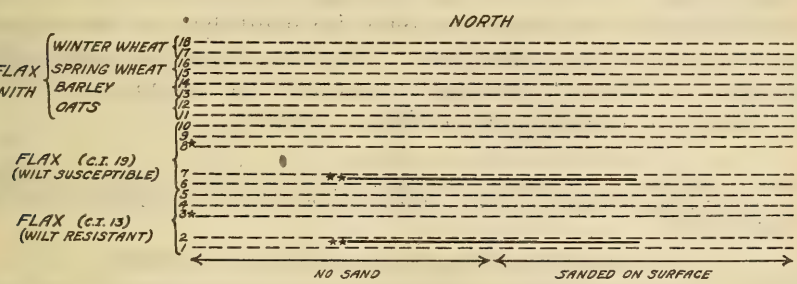


FIG. 1.—Plan of a typical plat in field experiments conducted at Fargo, N. Dak., in 1919, to determine the cause of flax canker of the nonparasitic type. Rows 3 and 8, marked with an asterisk (*), sown thinly at half the normal rate. Canvas strips 10 inches wide and 1 rod long were placed close to the flax rows marked with two asterisks (**) for shading from about 10 a. m. to 4 p. m., half on sanded area half on area not sanded.

rods long east and west and 10 feet wide north and south. It was divided into halves by a line extending north and south, and the soil of one of these halves was covered thinly with sand. The plat consisted of five rows each of two varieties of flax, North Dakota Resistant No. 114 (C. I. 13), a wilt-resistant variety, and Reserve (C. I. 19), a variety susceptible to wilt, and two rows each of flax with one of the cereals, oats, barley, spring wheat, or winter wheat, as a nurse crop. The rows extended east and west, so that each plant would be exposed to the sun's rays during the hottest part of the day and for the longest period possible. There was a 12-inch space between the second and third rows of each variety, and the third row of each variety was sown at half the usual rate. The other rows were spaced 6 inches apart. Half of the second row of each variety was shaded by placing just south of it a vertical strip of canvas 10 inches wide and 1 rod long. By this means the young plants were shaded from about

10 a. m. to 4 p. m. This typical arrangement of plats is represented diagrammatically in Figure 1.

Experimental plats of the kind described were sown at Fargo on May 22 (plat A), June 9 (plat B), June 27 (plat C), and July 18 (plat D). In plat A the shades unfortunately were not put in position until after canker had occurred. Canker occurred in plat A, not in plat B, to a slight extent in plat C, and not in plat D. Similar plats were sown at Mandan, N. Dak., on April 28, June 11, and July 1, except that where sand was applied at Fargo the soil was compacted at Mandan. Dry weather, cutworms, and grasshoppers made the results at Mandan unworthy of consideration.

While the canvas shades unfortunately were not put in position in plat A at Fargo until after canker had occurred on June 16, the presence and absence of weeds in different parts of the plat served much the same purpose in varying the amount of shade. Rows 1, 2, and 3 had been carefully weeded, while the rest of the plat was rather weedy. It was at once strikingly evident that by far the most canker occurred where the young flax plants had not been shaded by weeds or by the nurse crops. The data from this experiment are given in Table 2, showing a summary and comparison of the percentages of canker under different conditions.

TABLE 2.—*Results of experiments conducted at Fargo, N. Dak., to determine the effect of various types of shading of flax in sanded and unsanded ground on plat A, sown on May 22, 1919.*

[Data on the occurrence of heat canker of flax recorded on June 18, 1919.]

Conditions as to shading.	Without sand on surface.				Surfaced with sand.			
	Number of plants in row.	Plants cankered.			Number of plants in row.	Plants cankered.		
		Number.	Per cent.			Number.	Per cent.	
			Actual.	Average.			Actual.	Average.
No shade:								
Row No. 1	469	216	46.0	41.4	480	179	37.3	20.5
Row No. 2	411	168	40.9		467	80	17.1	
Row No. 3	188	70	37.2		277	21	7.6	
Shaded by weeds:								
Row No. 4	329	34	10.3	7.3	574	18	3.1	3.5
Row No. 5	461	34	7.4		433	17	4.0	
Row No. 6	361	25	6.9		198	10	5.1	
Row No. 7	355	10	2.8		159	6	3.8	
Row No. 8	147	10	6.8		80	2	2.5	
Row No. 9	189	33	17.5		288	7	2.4	
Row No. 10	308	5	1.6		115	4	3.5	
Shaded by weeds and grain:								
Row No. 11	637	19	3.0	4.3	333	0	0	1.9
Row No. 12	352	16	4.5		482	19	4.0	
Row No. 13	390	10	2.6		407	2	.5	
Row No. 14	379	11	2.9		236	1	.4	
Row No. 15	322	40	12.4		188	6	3.2	
Row No. 16	396	9	2.3		119	5	4.2	
Row No. 17	348	8	2.3		118	1	.9	

Table 2 shows that under three different conditions of shade more canker occurred on the heavy dark soil than on the same type of soil which had been covered with yellow sand a quarter of an inch in depth. It also shows that canker occurred most abundantly where the soil was shaded the least. This holds true in general both where sand was applied and where it was not used.

As already stated, no canker occurred on the later sowings in plats B and D, and only a limited occurrence was noted in plat C, sown on June 27, where the canvas shades were placed, as shown in Figure 1. The data obtained from this plat, taken when the plants were about 4 inches high, are summarized in Table 3.

TABLE 3.—*Number of flax plants cankered under various conditions in plat C, at Fargo, N. Dak., sown on June 27, 1919.*

[Data on the occurrence of heat canker of flax recorded on July 18, 1919.]

Row.	Shaded by canvas.		Not shaded.		Row.	Shaded by grain.	
	On sand.	No sand.	On sand.	No sand.		On sand.	No sand.
No. 1			0	3	No. 11	0	0
No. 2	0	0	0	4	No. 12	0	0
No. 3			1	23	No. 13	0	0
No. 4			0	2	No. 14	0	0
No. 5			2	10	No. 15	0	0
No. 6			2	3	No. 16	0	0
No. 7			0	2	No. 17	0	0
No. 8			0	0	No. 18	0	0
No 9			0	0			
No. 10			0	1			

It is evident from Table 3 that flax plants grown behind the canvas shades were not cankered, while some plants were cankered in the same rows when not shaded by the canvas, especially where sand was not applied. No flax was cankered where nurse crops were used. The row having the most cankered plants (No. 3) was the one sown thinly (at half rate) and double spaced from the next row on the south. While less canker occurred in this experiment, the results are in line with those obtained from plat A, presented in Table 2, in that the flax was cankered most where the soil was shaded least and where no sand was applied.

Experiments similar to those of 1919 were conducted during 1920, except that sand was omitted. A single variety resistant to flax wilt was used, and more variation was made in the rates of seeding. Six experimental plats were sown during the season at intervals of approximately two weeks. Canker appeared to a greater or less degree in the last four sowings. Plants emerging on May 28 or earlier were not cankered. The injury of plants in the plats where canker appeared occurred from 4 to 14 days after emergence. The data presented in Tables 4, 5, and 6 were obtained from the two plats in which cankered plants appeared in the greatest numbers.

Only traces of canker were observed in the other two plats. Table 4 shows the number of cankered plants occurring in rows sown at 3, 1.5, and 0.75 grams of seed per rod, with the rows spaced 10, 12, and 20 inches apart, respectively.

TABLE 4.—*Number of flax plants not cankered and cankered when grown in rows sown at three different rates and spaced differently at Fargo, N. Dak., in 1920.*

Plat.	Number of plants in rod rows.					
	Sown 10 inches apart, 3 grams per row.		Sown 12 inches apart, 1.5 grams per row.		Sown 20 inches apart, 0.75 gram per row.	
	Not cankered.	Cankered.	Not cankered.	Cankered.	Not cankered.	Cankered.
Plat G-1	1,088	143	536	125	191	119
Plat I-1	2,476	137	479	11	404	34
Total	3,564	280	1,015	136	595	153
Cankered plants ....per cent	.....	7	.....	12	.....	20

These data show that flax sown thinly cankered more than that which was sown thickly. This agrees with the results obtained in 1919, summarized in Table 3.

Table 5 presents data obtained in 1920 showing the influence of a nurse crop on the occurrence of flax canker. Barley was used as the nurse crop, and the flax was sown at the same rate as in the experiments without the nurse crop.

TABLE 5.—*Number of flax plants not cankered and cankered when grown without and with nurse crops, spacing and rate of seeding the same, at Fargo, N. Dak., in 1920.*

Plat.	Number of plants in plat.			
	Without nurse crop.		With nurse crop.	
	Not cankered.	Cankered.	Not cankered.	Cankered.
Plat G-2	1,088	143	1,084	86
Plat I-2	1,611	121	1,600	3
Total	2,699	264	2,684	89
Cankered plants ....per cent	.....	9	.....	3

These data show that less canker injury occurs to flax plants when partially shaded by a nurse crop than when sown at the same rate without such protection.

The data presented in Table 6 show the effect of shading the young flax plants by 10-inch vertical strips of canvas used in the same manner as in 1919, the data for which were presented in Table 3.

TABLE 6.—*Number of flax plants not cankered and cankered in plats not shaded and partially shaded by canvas, at Fargo, N. Dak., in 1920.*

Plat.	Number of plants in plat.			
	Not shaded.		Partially shaded by vertical strips of canvas.	
	Not cankered.	Cankered.	Not cankered.	Cankered.
Plat G-3	813	80	560	0
Plat I-3	282	20	181	0
Total	1,095	100	741	0
Cankered plants.....per cent	.....	8.4	.....	0

The results shown in Tables 3 and 6 are similar, in that flax plants grown behind canvas shades were not cankered, while some plants (8.4 per cent in 1920) were cankered in the same rows where not shaded by canvas.

It is to be regretted that apparatus was not at hand to take daily maximum soil-surface temperatures during the season of 1919. However, a limited number of soil-temperature readings were taken with ordinary thermometers. Six thermometers were placed under the various conditions in the plat and read at intervals. They were laid on the surface of the soil (or sand) and the bulbs barely covered with loose soil (or sand). The temperatures shown in Table 7 were taken on the same day at chosen places in the plat. Although the day was not one of the hottest of the season, it was hot enough to indicate the effect of shade and color of surface soil on soil-surface temperatures.

TABLE 7.—*Soil-surface temperatures, in degrees centigrade, taken in different parts of plat C, at Fargo, N. Dak., on July 18, 1919.*

Thermometer.	Location.	Time of day.						
		A. M.				P. M.		
		8.30	9.30	10.30	11.30	1.00	2.00	3.00
No. 1	On sand, in row	31	37	44	48	45	40	34.2
No. 2	On sand, between rows	30	35	40	45	45.5	41	36
No. 3	On sand, shaded by canvas	26	28	28.5	29	28	27	27
No. 4	On soil, in row	32	36	44	49	46.5	42	36
No. 5	On soil, between rows	33	39	44	49	47	43	37
No. 6	On soil, shaded by canvas	27	29	29	31	28	28	27.5

The data given in Table 7 and presented graphically in Figure 2 show that the rate of change of soil-surface temperatures on a hot day is much less rapid in the shade of a canvas 10 inches in height than on soil surfaces exposed directly to the sun's rays. This

explains why no canker occurred in those portions of the rows of young flax plants shaded by the vertical strips of canvas, while at the same time some plants were cankered in the portions of the rows not so shaded.

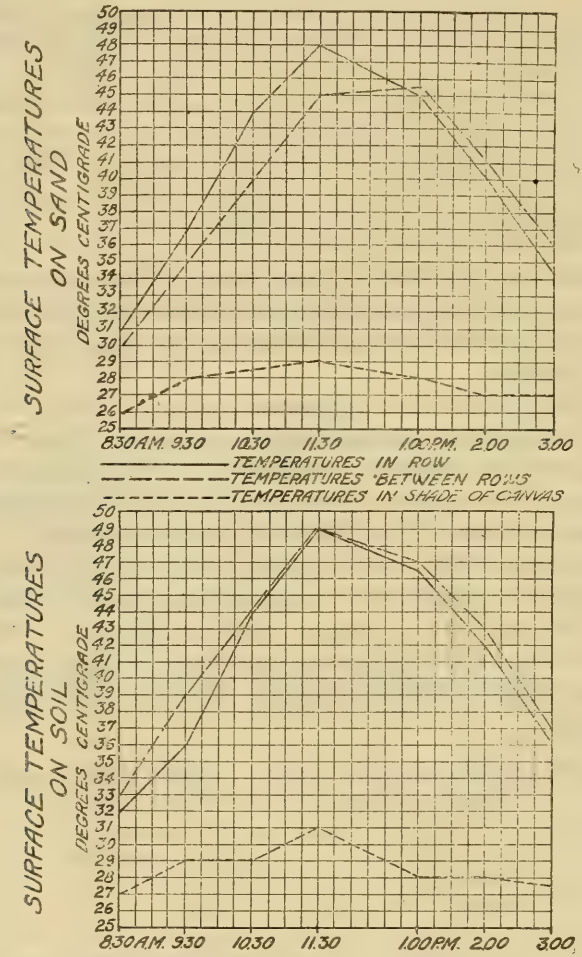


FIG. 2.—Diagram showing the variations in soil-surface temperatures in different parts of plat C at Fargo, N. Dak., on July 18, 1919.

Table 7 also shows that higher soil-surface temperatures occurred where the heavy dark soil had not received a surface application of light yellow sand. This probably explains why more canker occurred in the portions of the plats where sand had not been applied, as shown by the data in Tables 2 and 3.

On July 18, 1919, when the soil-surface temperature data shown in Table 7 were taken, the sun shone brightly until 2.30 p. m., when it became obscured by clouds. About 4 o'clock it began to rain. Previous to this the soil was fairly dry.

The temperature records for the seasons of 1920 and 1921 (Table 8 and Figs. 3 and 4) were taken with a soil thermograph the bulb

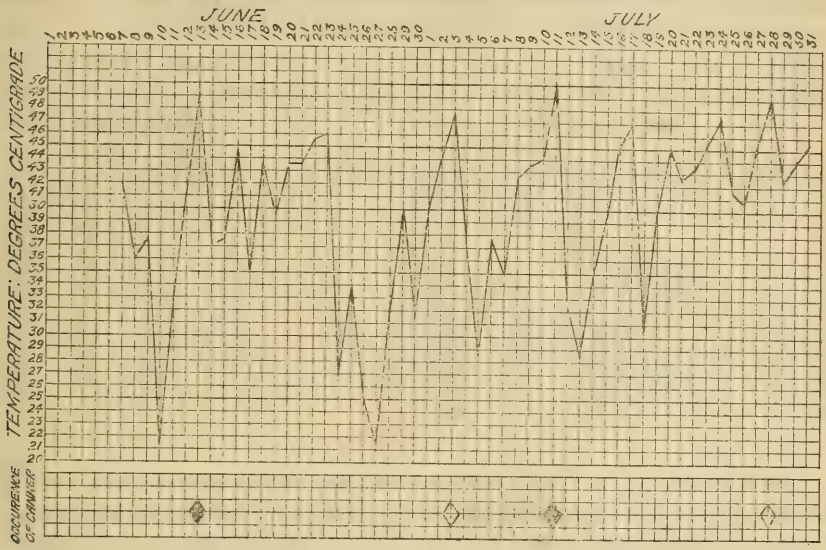


FIG. 3.—Diagram showing the daily maximum soil temperatures at a depth of half an inch, as recorded by a soil thermograph with bulb barely covered, at Fargo, N. Dak., during June and July, 1920 (see Table 8). The black diamonds show times when severe canker occurred and the white diamonds times when canker was slight.

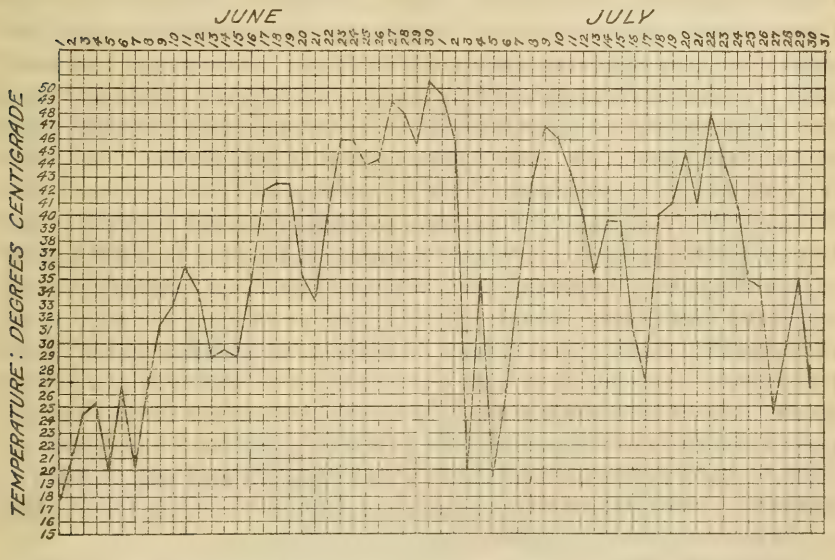


FIG. 4.—Diagram showing the daily maximum soil temperatures at a depth of half an inch, as recorded by a soil thermograph with bulb barely covered, at Fargo, N. Dak., during June and July, 1921 (see Table 8).

of which was buried in the surface inch of soil. No plants were allowed to grow within 4 feet of the bulb. This thermograph recorded the soil temperature at a depth of approximately half an inch.

TABLE 8.—*Daily maximum soil temperature in the heat-canker plat at Fargo, N. Dak., in June and July, 1920 and 1921.*

[Data in degrees centigrade, as recorded by a soil thermograph with the bulb barely covered, which corresponds to the soil temperature at a depth of half an inch.]

Day of month.	1920		1921		Day of month.	1920		1921	
	June.	July.	June.	July.		June.	July.	June.	July.
1	.....	40.0	17.5	49.5	17	35.0	47.0	42.0	27.0
2	.....	44.0	20.5	46.0	18	43.5	30.5	42.5	40.0
3	.....	47.5	24.5	20.0	19	39.5	40.0	42.5	41.0
4	.....	37.5	25.5	35.0	20	43.5	45.0	35.5	45.0
5	.....	28.5	20.0	19.5	21	43.5	42.5	33.5	41.0
6	.....	37.5	26.5	25.5	22	45.5	43.5	40.0	48.0
7	41.5	35.0	20.0	35.0	23	46.0	45.5	46.0	44.5
8	36.0	42.5	26.5	42.5	24	27.0	47.5	46.0	42.0
9	37.5	43.5	31.5	47.0	25	34.0	41.5	44.0	35.0
10	21.5	44.0	33.0	46.0	26	25.0	40.5	44.5	34.5
11	33.0	50.0	36.0	43.5	27	21.5	45.5	49.0	24.5
12	41.0	32.5	34.0	40.0	28	32.0	49.0	48.0	29.5
13	49.0	28.5	29.0	35.5	29	40.0	42.5	45.5	35.0
14	37.0	35.0	29.5	39.5	30	31.5	44.0	50.5	26.5
15	37.5	39.5	29.0	39.5	31	.....	45.5	.....	.....
16	44.5	45.0	34.5	31.0					

Data obtained in 1921 from maximum thermometers having the bulbs painted green showed that the soil-surface temperatures on hot days were considerably higher than the soil temperatures at the depth of half an inch. On the hottest days, that is, on June 27, June 30, and July 9, the soil-surface temperatures recorded by the maximum thermometers were respectively, 7, 4.5, and 7 degrees higher than the temperatures at a depth of half an inch recorded by the soil thermograph. Unfortunately, checks on the soil-thermograph records like these were not taken during 1920. However, if the averages of these corrections are transferred and added to the maximum soil temperatures as recorded by the soil thermograph on the days of high temperature in 1920, following which heat canker resulted, it is possible to approximate the temperatures that produced the canker. The four highest maximum soil temperatures in 1920, as will be noted from Table 9 and Figure 3, occurred on June 13, July 3, July 11, and July 28. Following each of these dates heat canker occurred on young flax plants in plats G, H, I, and J, which plats were sown periodically in order that young flax plants in at least one of these plats would be exposed at high temperatures on the hot days at any given time during the season. No canker occurred in any of the plats except the four mentioned and following high soil temperatures. These data are presented in Table 8 and Figure 3 and summarized in Table 9. They indicate that under conditions favorable for producing heat canker the critical temperature is about 54° C.

As shown in Table 9, only a few plants cankered in plats H and J, while many plants cankered in plats G and I (Table 4). In plat H the lack of severe injury probably was due to the fact that relatively old plants were subjected to comparatively low temperatures. Prob-

ably no canker would have occurred in this plat if the high temperature had not been preceded by a protracted period of wet, cloudy weather. This caused a somewhat succulent growth and also compacted the soil. In plat J the lack of severe injury probably was due to the fact that the plants were growing under hot, dry conditions and were not as succulent as the plants in the other plats in which canker occurred.

TABLE 9.—*Soil temperatures and severity of heat-canker injury produced on young flax plants at Fargo, N. Dak., on the four hottest days during June and July, 1920.*

Plat.	Number of days after plants emerged.	Date cankering occurred.	Maximum soil temperatures when canker occurred (° C.).		Average percentage of canker.
			Thermograph record at a depth of half an inch.	Approximate soil-surface temperature.	
Plat G	8	June 13	49.0	55.2	23.3
Plat H	14	July 3	47.5	53.7	Trace.
Plat I	4	July 11	50.0	56.2	4.7
Plat J	9	July 28	49.0	55.2	Trace.

In 1921 the investigations were continued in a similar manner both at Fargo and at Mandan, N. Dak. However, as will be seen in Table 8 and Figure 4, high soil temperatures did not occur until late in June, and therefore little, if any, flax canker developed before that time. Likewise, following the high soil temperatures in the last days of June and early July, but little canker developed, even though the soil-surface temperatures were sufficiently high to expect the production of canker in the late sowings. No doubt the lack of canker production under these conditions is chargeable to a combination of several factors, both from the standpoint of the condition of the young plants on the one hand and their environment on the other. Plants which had grown during the hot, dry weather of the latter part of June and early July were apparently not sufficiently succulent to be susceptible to canker injury from the high soil-surface temperatures. The soil throughout this period also was dry and unusually mellow, without any crust, and this also may have had some effect on the conditions governing the production of canker. It may be added that when the surface soil is mellow little air pockets tend to form immediately about the plants, in contrast to the close contact of the soil surface with the plant stems which occurs when the fine soil surface is compacted by rains and a thin crust is formed.

The soil crust caused by rains brings the surface soil in immediate contact with the tender surfaces of the succulent young flax stems. Injury results when such surface layers in immediate contact with the tender living tissues reach the high temperatures. This surface

crust may act as a conductor of heat to the plant. In contrast with this condition, when the top layer of the soil is mellow, which was the condition in late June, as previously pointed out, the little air pockets about the young plant stems tend to act as insulators and protect the stems from the high temperatures.

The evidence, therefore, indicates that heat canker of flax results from a combination of succulence in the young plants and high temperatures of the surface soil in immediate contact with such succulent tissues.

ARTIFICIAL PRODUCTION OF NONPARASITIC CANKER.

A cankered condition very similar to heat canker also has been produced artificially on flax. As agents, both chemicals and heat were used. On July 11, 1919, 50 plants (C. I. 191) were slightly burned at the soil line with concentrated sulphuric acid. At various intervals, from one to five minutes, the acid was washed off with water. Most of the plants died when the acid was left on as long as five minutes. By July 24 typical heat canker had developed on 17 of the plants that remained alive.

On July 20, 1919, the surface soil around seven flax plants was artificially heated. The flax plants were grown in pots and were 20 days old. A heavy aluminum wire about 14 inches in length was bent to form in its center a circular loop about 1 inch in diameter. The remainder of the wire led from this circle in two parallel adjoining strands. The circle of wire was placed in turn over each of the seven plants and buried slightly in the soil at the base of each plant in such a way that the plant was in the center of the loop. The flame from a Bunsen burner was applied to the ends of the wire until enough heat to produce injury was conducted by the wire to the soil immediately surrounding the plant. In about eight days a few of these plants showed typical heat canker.

On July 29, 1919, 12 young flax plants were slightly injured by electrically heated wire. A loop of fine copper wire was placed around each plant, barely touching the stem at the soil line, and an electric current (110 volt, alternating) was passed through it. The wire was immediately burned out, but the heat for the instant was sufficient to cause slight injury. One flax plant of the twelve showed typical heat canker on August 7.

SIMILAR INJURY TO OTHER PLANTS.

Similar maladies have been described or observed on various plants. In one instance the senior writer noted in a field of buckwheat in central Montana a malady similar to heat canker of flax. The buckwheat plants having the most typical symptoms were in a portion of the field where the stand was thin. Later examination showed no evidence of fungous attack.

At Fargo, N. Dak., about June 10, 1921, the junior writer and Prof. H. L. Bolley observed similar injuries on wheat and barley seedlings. Similar injuries were reported also about the same time from other parts of North Dakota on these crops and also on oats. (For soil temperatures, see Fig. 4.)

Hartley (*7* and *8*) described basal lesions due to excessive heat on seedlings of conifers, rye, and cowpeas. He found that the surface layer of the soil in a Nebraska nursery attained a temperature of 52° C. even in the half-shade of a lath frame. The very young conifer seedlings were injured at the soil surface, where a constriction formed. Later they fell over and died. The lesions usually became white, and for this reason he called the trouble white-spot.

MacMillan and Byars (*10*) observed a heat injury to beans in Colorado. The stems were shrunken at the ground line, and many of the young plants fell over.

Münch (*12*, *13*, and *14*) reported soil-line heat injury on maple, vetch, and peas and thought that in some cases germinating seeds, as well as seedlings already emerged, are killed by overheated soil. The death point for vegetative plant cells, according to Mayr (*11*) and Münch, lies at 54° C. Münch records a soil-surface temperature as high as 62° C. in sandy soil and states that temperatures of 50° to 55° C. are reached almost daily in such soils during clear weather. Schuster (*20*) found a stem girdling of young plants in German East Africa which corresponds very closely to descriptions of heat injury by Münch and Tubeuf (*21* and *22*).

Ramann (*17*) has seen large numbers of year-old oaks killed off by heat girdling in the steppes of south Russia and has recorded there soil-surface temperatures higher than 60° C.

Hartig's (*6*) temperature measurements of a spruce in August show how much the parts of plants are warmed above the air temperatures. A temperature of 55° C. was found in the cambial region of the southwest side when the air temperature was 37° C.

Mayr (*11*) states that free-lying soil, especially if dark colored, as is the case when it is rich in humus, can attain high temperatures. He found the maximum temperature to be 68° C. In another case he found a temperature of 58° C. at 49° latitude and at an elevation of 1,870 feet.

Tubeuf reports soil-surface temperatures above 60° C. in the United States.

PREVENTIVE MEASURES.

Assuming that the consistent losses from flax canker in the semiarid northern section of the Great Plains area are due to excessive heat, any remedial measures would be in the nature of practices which would prevent the overheating of the surface layer of the soil during the seedling stage or would bring the plant past the stage of

susceptibility to injury before the excessive heat occurs. Investigations along these lines are being continued by the Office of Cereal Investigations in cooperation with the North Dakota Agricultural Experiment Station. Tentative suggestions for lessening this injury are (1) higher rates of seeding, (2) earlier dates of seeding, and (3) drilling north and south rather than east and west. In this connection it is well to remember that the beginning of these intermittent periods of overheating in this section usually occurs in the first or second week of June.

SUMMARY.

Investigations have shown that the cause of the heat-canker type of flax injury is nonparasitic in its nature.

It occurs somewhat uniformly each year in the northern Great Plains area and causes a marked loss in flax production.

The cortex of the stem is killed at the surface of the ground. Sooner or later the cankered plants topple over. Young cankered plants die at once, while those that are a little older may remain alive for days or weeks, as long as the vascular systems function. Stems of the older cankered plants usually enlarge just above the injury, and sometimes also just below it. The result is a girdling of the plants at the soil line.

In these experiments and observations flax was cankered only during and immediately following very hot days. Flax plants when more than 4 inches high are only slightly susceptible. Flax plants which have developed under hot, dry conditions are less susceptible to injury from high soil-surface temperatures than more succulent plants.

Flax plants which are grown in a soil having a shallow surface mulch over a firm seed bed are less readily injured than those grown in a soil in which the surface layer has been compacted into a crust by rains. Plants shaded by a vertical strip of canvas 10 inches high were not cankered, while many unshaded plants in the same row were cankered. Thinly sown flax was cankered more than thickly sown flax.

Flax sown with cereals as nurse crops was cankered comparatively little, and flax with weeds was cankered less than flax free from weeds.

Evidence indicates that heat canker of flax results from a combination of succulence in the young flax plants and high temperatures of the surface soil in immediate contact with the succulent stem tissues.

Killing the cortex of young flax plants by artificial heat produced typical heat canker.

Promising control measures seem to be thicker seeding and early sowing, and possibly drilling rows north and south instead of east and west may prove helpful in lessening the severity of canker injury.

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THE EFFECTS OF INBREEDING AND CROSS-BREEDING ON GUINEA PIGS.[1]

III. CROSSES BETWEEN HIGHLY INBRED FAMILIES.

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INTRODUCTION.

It has been shown in Part I of this series of papers[2] that continuous mating of brothers with sisters in a stock of guinea pigs has been accompanied by a decline in all of the elements of vigor which have been studied. These include the percentage born alive, the percentage raised to weaning (33 days), birth weight, rate of gain to weaning, adult weight, size of litter, and number of litters produced per year. Just how much of the decline in these respects was due to inbreeding and how much to environmental conditions was not wholly certain. It was shown, however, that the inbred stock had

[1] The two preceding parts of these studies have been published as Bulletin 1090, U. S. Department of Agriculture.

come to be distinctly inferior to a control stock in all of these respects and also in resistance to tuberculosis. It was concluded from a consideration of the various lines of evidence that the inbreeding was in some way responsible for at least a part of the decline.

In Part II [2] a detailed study was made of the 23 separate inbred families. It was shown that marked hereditary differentiation had been brought out among them early in the course of the inbreeding and that the differences had increased later. There had been also an automatic differentiation and fixation of the more obvious characteristics, such as color, pattern, and tendency toward polydactylism and toward the production of particular types of monsters. It was found that the various elements of vigor and weakness had become fixed in almost every possible combination in the various families, there being no evidence for hereditary differences in general vigor.

The purpose of the present paper is to present the results of crosses between the inbred families.

THE INBRED FAMILIES.

Of the 17 inbred families still in existence in 1916, only 5 have been retained to the present. It seemed necessary to eliminate the others in order to make room for the crossbreeding experiments and to obtain sufficient numbers from these five. Families 2, 13, 32, 35, and 39 were the ones retained, partly because they occupied a large number of pens, and partly because of contrasting characteristics. Family 39, for example, had the least white in the coat, while Family 13 had the most. Family 32 had a peculiar intense golden agouti. Families 2 and 13 were at opposite extremes in weight and also contrasted in size of litter.

CROSSBREEDING EXPERIMENTS.

The control stock, Experiment B, has been maintained, as from the first, by matings between individuals less closely related than second cousins.

Since 1916 a large number of first crosses have been made between different families. These constitute Experiment C0. The young are crossbred but the parents are inbred.

Some of the progeny from Experiment C0 have been mated with others from a different cross, thus bringing together four inbred families. This is Experiment CC. Both parents and young are crossbred in this case.

Other animals from Experiment C0 have been mated brother with sister. This is Experiment C1. The parents are crossbred but the young are to some extent inbred.

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[2] U. S. Department of Agriculture Bulletin 1090.

This renewed inbreeding has been continued in a small second generation of brother-sister mating, Experiment C2, in which both parents and offspring are, to some extent at least, again inbred.

In Experiment CA, inbred females were mated with crossbred males derived from two other inbred families. Experiment AC is the reciprocal, crossbred females mated with unrelated inbred males. The progeny of these two experiments should have approximately the same heredity. Differences in the results must be attributed to the direct influence of the dam or sire.

The nature of these experiments is indicated in Table 1, in which the result of prolonged inbreeding is represented by 0, crossbreeding by 1, and the first and second generation of renewed brother-sister mating by ½. It will be shown later that these figures represent accurately the differences to be expected among the experiments.

TABLE 1.—*The breeding of the sire, dam, and young in the various experiments.*

Items.	B.	Inbred.	C0.	CA.	AC.	CC.	C1.	C2.
Heredity of sire	1	0	0	1	0	1	1	½
Heredity of dam	1	0	0	0	1	1	1	½
Heredity of young	1	0	1	1	1	1	½	½

Two selection experiments were begun in 1918 among the crossbreds derived from the inbred stock. In Experiment CG only animals which were exceptionally heavy at weaning at 33 days were used (average weight, males, 307.7 grams; females, 298.1 grams). These naturally came in the main from small litters (average 1.7). In Experiment CL only animals from large litters were mated (average 4.3). These were generally light in weight (average, males, 214.1 grams; females, 207.0 grams), and seemingly much less thrifty than those in CG. In both cases, animals were chosen from any crossbreeding experiment (except B) and in a few cases from among the inbreds. The experiments were discontinued after 1919. While not carried on long enough to be satisfactory as selection experiments, they are of interest as throwing light on the question as to how far any conscious or unconscious selection of young on the basis of vigor could account for the observed difference between experiments.

DESCRIPTION OF TABLES.

The results in the various experiments during the years 1916 to 1919 are shown in detail in Tables 14 to 21 and are summed up in Table 29.

Table 14 gives data on the fertility. The number of litters and the average size of litter are given for each experiment. The number of mating years was calculated as described in Part I.[3] Each mating

[3] U. S. Department of Agriculture, Bulletin 1090.

was entered as mature under the month in which the male reached 4 months of age or under the month following mating if he was already 3 or more months old. The mating was dropped in the month following the death or disposal of the female. The number of months of mating in the experiment, divided by 12, gives the number of mating years with sufficient accuracy for use in calculating the average number of litters per year, young per year, and young raised per year, which are given in the last three columns of Table 14.

Table 15 presents data on the percentage of the young born alive (or at least found alive) in each experiment during the years 1916–1919. The total percentage is given in the next to the last column. This is not necessarily the best measure of the relative standing of the experiments in success in bearing living young under fixed conditions, as has been discussed in Part I. The percentages are accordingly given separately for each size of litter and an index is given (last column) for the purpose of showing the standing of the experiments free from the influence of size of litter. In the present paper this index is derived by assigning weights of 1, 3, 3, and 1 to the records of litters of 1, 2, 3, and 4, respectively.

The desirability of using such an index may be seen by comparing the records of the first two inbred families (Nos. 2 and 13). Family 13 is superior to Family 2 in the percentage born alive in each size of litter except in litters of 4, yet in total percentage born alive it comes out markedly inferior. The explanation is merely that Family 13 produced a greater number of large litters. The index brings out better the true relation under constant conditions.

So far as the crossbreeding experiments are concerned, it makes very little difference whether the total percentage or the index is used. This is because size of litter has less effect on mortality of the young than among the inbreds.

There are, of course, other conditions which affect the percentage born alive, the uniformity of which must be considered before making a final interpretation of the results. The more important of these conditions will be taken up later after consideration of the other tables.

The data on the percentage raised to 33 days of the young born alive are presented in a similar way in Table 16. The index given in the last column is derived in the same way as described above. The product of these percentages, the percentage raised to 33 days of all young born, is treated in the same way in Table 17.

In the case of birth weight (Table 18) the effect of size of litter is so great that the actual average in an experiment means very little. The average birth weight in one of the inbred families (No. 35), for example, is greater than that in Experiment AC (72.6 compared with 72.1). This, however, is not as significant as the fact

that AC is markedly superior in the average for any given size of litter. The latter fact is brought out in the index, obtained as in the cases of the mortality percentages, by assigning weights of 1, 3, 3, and 1 to litters of 1, 2, 3, and 4, respectively.

The differences among the experiments in the percentage of the young which die before weaning have an effect on their standing in average birth weight, since such young are in general below the average. The average birth weight of the young which reach 33 days (Table 19) thus gives a better measure of the normal prenatal growth rate and also is needed in calculating the rate of gain between birth and weaning.

The averages and indices for weight at weaning (33 days) are dealt with in Table 21. The rate of gain between birth and weaning, obtained from the data in Tables 19 and 21, is given in Table 20.

ALLOWANCE FOR SEASONAL FLUCTUATIONS.

Size of litter is of course not the only factor for which allowance must be made in studying the effects of breeding on the various characters. The most important factor is undoubtedly the environmental situation. It would be highly desirable to compare the records only in experiments which were conducted simultaneously and under the same conditions. There are, however, practical difficulties in carrying through such a project. Some of the present experiments were carried on through the whole four years 1916–1919, but others were started or dropped at intermediate times. Table 22 shows the average number of mature matings in each experiment during each 3-month period, beginning with January to March, 1916, and ending October to December, 1919. The number of litters, the number of young, the number of young born alive, and the number raised in each experiment during each of these periods are shown in Tables 23 to 26.

The environmental conditions were unfortunately exceptionally varied during the four years which we are considering. There were three times—the winters of 1915–16 and 1916–17 and the spring of 1918—when the stock did very poorly, due partly to unusual winter conditions, extreme variations in temperature, poor ventilation, etc., but probably in the main to insufficient green feed. In all of these periods symptoms, such as lameness and bleeding at the gums, appeared, which were probably indications of scurvy. There have been no real epidemics of contagious disease, although many old animals died in the periods noted above. The stock reached fairly good condition during each fall; and good condition was maintained through all of 1919.

The records of the total inbred stock have been tabulated for each 3-month period during 1916 to 1919. A summary of the indices and

averages is given in Table 27. The results are presented graphically in Figures 1 to 7. The periods of depression and of good condition are clearly brought out. In a general way there is agreement between the fluctuation of the percentage born alive, the percentage raised of those born alive, birth weight, rate of gain, and size and frequency of litters. Figure 6, which shows the number of young raised per year by the average mating in each period, perhaps reveals best the changes in environmental conditions. The probable absence of relation between sex ratio and season may be seen by comparing Figure 7 with Figure 6.

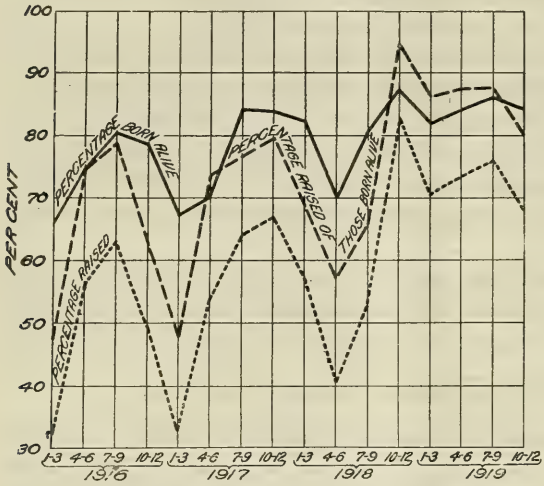

FIG. 1.—The percentages born alive, raised of those born alive, and raised of all young, in the inbred stock during successive 3-month periods, 1916–1919.

There are various ways in which allowance could be made for these fluctuations. The method which has been adopted is to compare the actual average or index for each experiment for the entire period in which it was maintained with the estimated record of the total inbred stock produced simultaneously. As an example, we see in Table 22 that there were 0.3 mature matings in Experiment C1 in the period July–September, 1916. The record of the inbreds as regards frequency of litter during this period is given in Table 27 as 3.35. Multiply these together and add the similar products for subsequent periods in the history of C1. On dividing by the total number of mature matings (3 months'

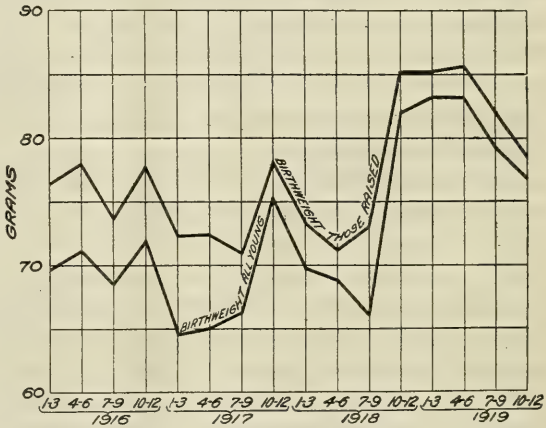

FIG. 2.—The average birth weight of young raised to weaning (33 days) and of all young born in the inbred stock during successive 3-month periods, 1916–1919.

duration) we obtain the desired estimate for inbreds producing litters simultaneously with Experiment C1.

In dealing with other characteristics, the number of matings present in each 3-month period does not necessarily provide the proper weights to be applied to the records of the inbreds. Litters per year, young per year, and young raised per year are properly weighted by the number of matings, but in the case of size of litter the number of litters produced by the given experiment in each 3-month period (Table 23) should be used. The percentage of young born alive, the percentage raised of all born, and the birth weight of all born should be weighted by the number of young born in each 3-month period as given in Table 24. There is a slight impropriety here, owing to the use of indices for these characters, but it is of no practical importance. Similarly the percentage raised of the young born alive is to be weighted by the numbers born alive, shown in Table 25. The birth weight of the young raised, the rate of gain to weaning, and the weight at weaning are to be weighted by the numbers weaned in each period, shown in Table 26. The estimated record of the inbreds, simultaneous with each experiment, is shown for each character in Table 28.

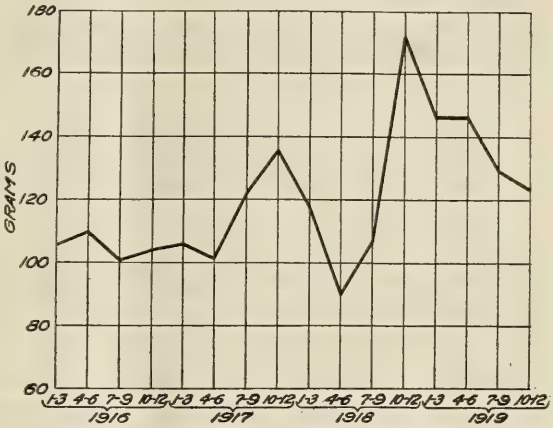

FIG. 3.—The average gain between birth and weaning (33 days) in the inbred stock during successive 3-month periods, 1916–1919.

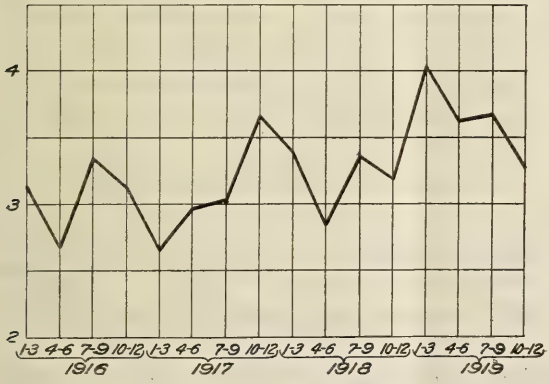

FIG. 4.—The average number of litters produced per year by mature matings in the inbred stock during successive 3-month periods, 1916–1919.

This method of correcting for the seasonal fluctuations rests on the assumption that the condition of the total inbreds was genetically constant during the four years. Theoretically one would expect practical constancy in each family after a dozen generations of brother-sister mat

ing. The records in four previous years, 1911–1915, as well as in these years show that the total inbred stock rose and fell in close parallelism with the control stock. The rising records for the years 1916–1919 certainly give no evidence of continued genetic decline. It would have been desirable to have used only one family as a criterion of the rise and fall in environmental conditions if sufficient numbers had been available. As it was, it seemed best to use the total inbred stock. This stock was largely composed of five families which were kept up to about the same proportional representation during this period. The combined averages for the other families, moreover, were close in most respects to the average of these five important families.

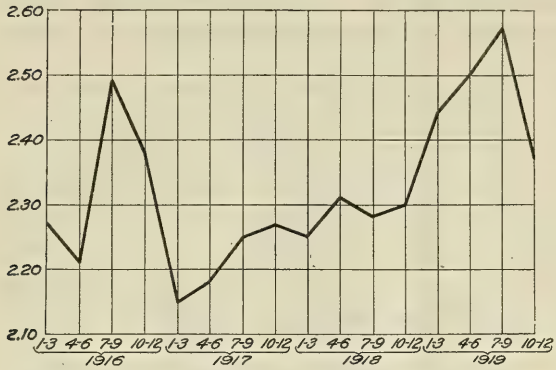

FIG. 5.—The average size of litters produced by the inbred stock in successive 3-month periods, 1916–1919.

A comparison of the entries in Table 28 with the corresponding ones in Table 29 brings out, it is believed, the superiority or inferiority of each experiment to the total inbred stock, free from the influence of seasonal fluctuations and of size of litter on the other characters.

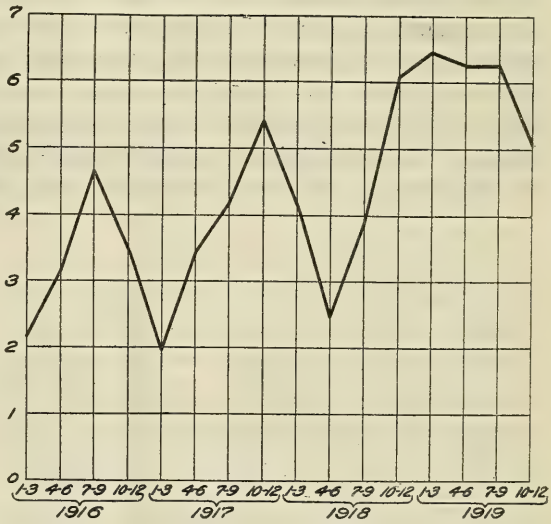

FIG. 6.—The average number of young raised per year, by mature matings, inbred stock, during successive 3-month periods, 1916–1919.

TABLE 2.—*The superiority (+) or inferiority (−) of the record of each experiment to that made by the inbred stock at the same time.*

[With respect to the first three characteristics (percentage born alive, percentage raised of those born alive, and percentage raised) the difference from the record of the inbred stock is corrected as described in the text. With respect to the other characteristics, the differences are given as percentages of the record of the inbred stock.]

Experiment.	Percent born alive.	Percent raised of those born alive.	Percent raised.	Birth weight, total.	Birth weight, those raised.	Gain.	Weight at 33 days.	Size of litter.	Litters per year.	Young per year.	Young raised per year.
2	−3.8	+3.3	−0.3	−9.4	−7.7	−18.6	−14.4	−3.6	+12.9	+8.8	+13.1
13	−1.4	−1.5	−2.8	+3.4	+6.1	+13.2	+10.4	+7.8	0	+7.8	+2.1
32	+2.3	−6.0	−2.3	+2.3	+0.8	+0.3	+0.4	−6.5	+1.5	−5.1	−7.8
35	+0.7	+4.3	+3.3	+5.8	+4.6	+11.8	+9.0	+4.2	+9.7	+14.3	+16.1
39	+4.3	−5.3	−0.4	−4.6	−5.2	−1.1	−2.6	+1.0	−8.4	−7.5	−11.9
Other	+1.0	−1.6	−1.6	+2.8	+1.6	+0.6	+1.0	−1.6	−11.9	−13.3	−15.2
CO	+0.5	+11.2	+9.2	+1.7	+2.5	+13.2	+9.0	−1.8	+0.8	−1.0	+9.5
CA	+2.7	+12.4	+10.4	+3.6	+3.6	+11.7	+8.6	+3.6	+19.4	+23.6	+47.4
AC	+7.6	+11.8	+14.7	+8.8	+8.1	+11.9	+10.5	+28.3	+9.3	+40.2	+63.7
CC	+6.9	+12.0	+14.6	+12.9	+9.2	+21.0	+16.5	+14.3	+36.1	+55.4	+82.5
C1	+9.0	+9.3	+13.9	+10.7	+7.1	+15.9	+12.5	+10.2	+33.3	+46.9	+73.1
C2	+3.8	+7.9	+8.9	+6.7	+4.5	+12.7	+9.8	+4.0	+25.0	+29.9	+43.7
CL	+9.8	+4.8	+11.5	+8.3	+4.5	+21.7	+15.3	+14.2	+17.8	+34.5	+56.2
CG	+5.1	+5.9	+8.8	+8.0	+8.4	+19.5	+15.3	+15.1	+27.0	+46.1	+53.4
B	+8.6	+10.8	+14.9	+10.8	+9.4	+18.9	+15.2	+14.0	+14.1	+30.1	+60.2

The actual differences are shown in Table 30. In Table 2 the differences in the case of the weights and fertility are shown as percentages of the record of the total inbred stock. Experiment B, for example, produced litters 14 per cent larger than the inbreds. In the case of the mortality data, the actual differences shown in Table 29 are modified to allow for the influence of different basic percentages in the inbred stock. To illustrate, 69.4 per cent was the percentage of the inbreds raised to 33 days while Experiment AC was in progress. Only 58.9 per cent were being raised simultaneously with CC. There is more room for improvement in the latter case. Thus the 8.2 per cent advance of AC beyond the inbreds may mean as much as the advance of 11.9 per cent shown by CC. A correction has been applied according to the method described in a previous paper (Wright, 1920)[4] in connection with the percentage of white in the coats of guinea pigs. Assume that the distribution of the animals in a given stock relative to conditions which make for survival or death follows approximately a normal probability curve. The area to one side of a certain ordi-

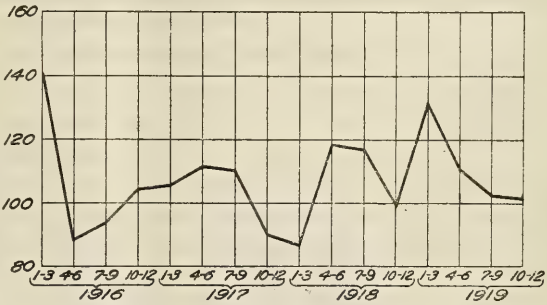

FIG. 7.—The sex ratio (number of males per 100 females) among the young born in the inbred stock during successive 3-month periods, 1916–1919.

[4] See "Literature cited" at end of bulletin.

nate represents the percentage of deaths, to the other side, survivals. The change in the percentage of deaths due to a given shift in the conditions is equal to the area between two ordinates at a given distance apart. This area is of course greater at the middle of the curve (50 per cent deaths) than toward either limit. On this hypothesis a table of probability integrals can be used for comparing percentage differences at different points of the range between 0 per cent and 100 per cent.

The numbers in Table 2 give the departure of each experiment from the total inbred stock, adjusted on the above basis to the record of the latter for the whole four years 1916–1919, i. e., 77.7 per cent born alive, 72.1 per cent raised of those born alive, and 56.3 per cent raised. This correction, it will be noticed, makes the records of AC and CC, with which this discussion started, approximately equal. So far as most of the conclusions are concerned, it makes little difference whether the correction is made or not. It seems important, however, to show the order of effect.

ALLOWANCE FOR HEREDITY.

Another consideration, which has doubtless occurred to the reader in comparing the records of the inbreds and crossbreds, is the exact heredity of the latter. There are fairly large differences among the inbred families themselves. If only animals from the better families were used in making crosses, the latter would naturally be superior, apart from the effect of the system of mating.

TABLE 3.—*The inbred ancestry of the males and females used in the various crossbreeding experiments, in percentages.*

[Each mating weighted by the number of litters produced through 1919.]

Inbred family.	C0.		C1.	C2.	CC.		CA.		AC.	
	Sire.	Dam.			Sire.	Dam.	Sire.	Dam.	Sire.	Dam.
2	16.1	19.3	9.7	8.0	5.4	5.8	20.9	18.4	16.9	27.0
13	7.7	23.6	16.1	8.0	16.3	23.7	21.8	42.4	18.0	15.2
32	5.3	7.2	4.2	5.3	5.6	2.9	8.5	26.6	15.7	7.0
35	11.1	5.1	6.5	0	7.5	4.2	9.8	12.0	27.3	7.0
39	16.6	7.9	18.3	18.7	21.0	17.7	17.7	0.6	17.4	17.3
7	4.8	2.7	0.6	0	1.0	2.5	0	0	0	3.2
9	3.1	3.8	4.7	5.3	0	1.0	0.9	0	0	2.0
17	3.8	6.8	8.7	12.0	6.5	1.0	1.3	0	3.5	0.6
18	4.1	1.2	3.0	0	0.6	2.5	1.3	0	0	2.9
20	4.1	6.5	3.6	8.0	3.5	5.8	2.5	0	0	5.3
23	7.0	2.1	2.4	0	7.9	4.2	2.5	0	0	1.7
24	0	0.9	0	0	0	0	1.3	0	0	0
31	4.6	2.7	4.4	10.7	4.0	5.0	1.6	0	0	1.7
34	3.8	1.7	2.8	0.7	10.5	7.9	9.5	0	0	1.2
36	5.5	4.1	6.7	8.0	5.4	4.0	0	0	0	4.7
38	2.4	4.4	8.3	15.3	4.8	11.8	0.3	0	1.2	3.2
OI	43.2	36.9	45.2	60.0	44.2	45.7	21.3	0	4.7	26.5

As it was, however, an effort was made to use all of the families. So far as any preference was given it was to the weaker ones. The inbred ancestry of the sires and dams of the litters produced in each

crossbreeding experiment is shown in Table 3 by percentages. These percentages can be applied to the differences between each inbred family and the total inbred stock as shown in Table 2 in order to find the extent to which the ancestry of the various crossbreeding experiments was above or below the average.

TABLE 4.—*The estimated superiority (+) or inferiority (−) of the inbred ancestors of the crossbreds to the total inbred stock.*

[The figures are based on the percentages given in Table 2 and may be compared with the actual superiority of the crossbreds over the inbreds as shown in that table.]

Experiment.	Per cent born alive.	Pern cent of those born alive.	Per cent raised.	Birth weight (total).	Birth weight of those raised.	Gain.	Weight at 33 days.	Size of litter.	Litters per year.	Young per year.	Young raised per year.
C0:											
Sire	+0.6	−1.0	−0.8	0.0	−0.4	−0.6	−0.5	−0.4	−3.3	−3.7	− 4.9
Dam	−0.2	−0.9	−1.3	+0.1	+0.4	+0.3	+0.3	+0.4	−2.0	−1.6	− 3.3
CA:											
Sire	+0.1	−1.0	−1.0	−0.7	−0.3	+0.1	−0.1	+0.6	−0.3	+0.3	− 1.2
Dam	−0.6	−1.1	−1.5	+1.0	+1.9	+3.7	+2.9	+1.4	+3.9	+5.2	+ 3.1
AC:											
Sire	+0.4	−0.5	−0.2	+0.3	+0.4	+2.3	+1.5	+1.0	+3.0	+4.1	+ 3.0
Dam	0.0	−0.8	−0.9	−1.5	−1.2	−2.2	−1.8	−0.2	−0.3	−0.6	− 1.6
CC:											
Sire	+1.1	−1.9	−1.2	+0.9	+0.6	+2.1	+1.5	+0.5	−5.5	−4.9	− 7.4
Dam	+0.8	−1.8	−1.4	+1.0	+1.0	+2.6	+2.0	+1.1	−5.7	−4.6	− 7.4
C1	+0.8	−1.6	−1.2	+0.5	+0.3	+1.2	+0.9	+0.4	−5.0	−4.6	− 6.7
C2	+1.1	−2.1	−1.4	+0.5	−0.1	−0.3	−0.2	−0.8	−7.6	−8.3	−10.5

The results are shown in Table 4. It will be seen that while the ancestors of the crossbreds were slightly above the average in some respects, as in weight and percentage born alive, in other respects they were below the average, notably in frequency of litter and the characteristics which depend on it.

In all important cases the corrections which might be made are small compared with the actual differences among the experiments. It is clear that these differences are not due to selection of superior inbred families in making the crosses.

In the case of the selection experiments CG and CL, the most important consideration relative to ancestry is the degree to which they were derived from different crossbreeding experiments. This is shown in Table 5.

TABLE 5.—*The origin of the males and females used in experiments CL and CG, in percentages.*

[Each mating weighted by the number of litters produced through 1919.]

Experiment.	CL.		CG.		Experiment.	CL.		CG.	
	Sire.	Dam.	Sire.	Dam.		Sire.	Dam.	Sire.	Dam.
Inbred	5.2	4.5	0	1.0	AC	12.7	16.4	1.5	11.4
C2	9.0	0	3.0	9.4	CC	15.7	16.4	18.8	12.9
C1	33.6	32.1	5.9	20.8	CL	17.9	18.7	0	0
C0	3.7	11.9	26.7	21.8	CG	0	0	36.1	22.8
CA	2.2	0	7.9	0					

ALLOWANCE FOR AGE OF DAM.

Another conceivable cause of differences among the experiments is the percentage of litters produced by immature females. The percentage of first litters in each experiment is shown in Table 6.

TABLE 6.—*The first litters from immature parents (mated at one or two months of age) as percentages of the total number of litters (1916–1919).*

Experiment.	Per cent.	Experiment.	Per cent.	Experiment.	Per cent.	Experiment.	Per cent.
2	14.3	39	15.3	CO	21.6	C1	20.5
13	18.8	Other	16.2	CA	23.8	C2	25.3
32	18.4	Inbred	17.4	AC	20.1	CL	25.4
35	22.3	B	8.3	CC	16.8	CG	23.8

Assuming that first litters are at a disadvantage, Experiment B should be superior to the inbreds, Experiment CC should be practically the same, while the other crossbreeding experiments should be inferior. However, as pointed out in Part I, the slight inferiority of first litters found in the present stock of guinea pigs is almost wholly a seasonal complication. A majority of the matings have been made in summer and fall under favorable conditions, bringing a majority of the first litters in winter and spring, when conditions are apt to be poor. It is found that on making proper correction for season, the low records for first litters born when the female is about 6 months old, as well as the similarly low records near 18 months of age, are brought almost to the 12-month and 24-month levels. It may safely be asserted that the differences in the average age of the dams in the various experiments are negligible as causes of differences in their records.

ALLOWANCE FOR SEX.

There is a slight difference between the birth weight of males and females and a slightly greater difference in their weaning weights. Since, however, the sex ratio (Table 7) in no case departs widely from equality, it has not been deemed necessary to find separate averages for the sexes.

TABLE 7.—*Sex of young born in each experiment, 1916–1919.*

[Those of unknown sex were in general found dead and in bad condition.]

Experiment.	Males.	Females.	Sex unknown.	Total.	Males per 100 females.	Experiment.	Males.	Females.	Sex unknown.	Total.	Males per 100 females.
2	514	444	40	998	115.8	CC	297	303	17	617	98.0
13	350	361	29	740	97.0	C1	302	317	10	629	95.3
32	237	245	6	488	96.7	C2	94	87	1	182	108.0
35	429	398	6	833	107.8						
39	195	177	10	382	110.2	CL	183	186	12	381	98.4
						CG	285	277	19	581	102.9
Other	564	567	39	1,170	99.5						
Inbred	2,289	2,192	130	4,611	104.4	B	761	762	36	1,559	99.9
CO	653	647	34	1,334	100.9						
CA	206	202	2	410	102.0	Total	5,341	5,262	272	10,875	101.5
AC	271	289	11	571	93.8						

There are certain interrelations among the characters, such as between percentage born alive and percentage of those raised, and between frequency and size of litter, of which account will be taken later in interpreting the results.

SIGNIFICANCE OF DIFFERENCES.

The records of the various experiments have now been corrected for the effects of size of litter and seasonal conditions, and it has been shown that no other important corrections need be made. It remains to be shown that the resulting differences (Table 30) are statistically significant.

The general significance of the differentiation among the inbred families has already been shown (Part II, Bulletin 1090) through the existence of high correlations between the records of the families in 1916–1919, and their records in 1911–1915 and 1906–1910. The considerably greater differences among the experiments relative to the system of mating fall into a consistent scheme which of itself leaves little doubt as to the general significance.

As to particular cases, the probable error of size of litter has been calculated by the usual formula, $PE = .6745 \frac{\sigma}{\sqrt{n}}$ where σ is the standard deviation, which may be calculated from the data in Table 14 and n is the number of litters.

The same type of formula has been used in the cases of litters per year, young per year, and young raised per year. If n is the number of mating years, σ is the standard deviation of number of litters, number of young, or number of young raised, respectively, during a year. An estimate of these standard deviations was made by tabulating the records for the first year after maturity for all matings which lasted at least 12 months. The records for the second and third full years were also used where available. The means and standard deviations were calculated for each group (Families 2, 13, etc., Experiments CO, CA, AC, etc.). As the standard deviations of these individual groups were rather irregular, owing to small numbers, it seemed best to use the average standard deviations in calculating the probable errors, making allowance for the correlation between mean and standard deviation, a correlation which is very important in the case of litters per year. Combining all of the above data, there was an average of 3.77 litters per year, 9.27 young per year, and 6.56 young raised per year. Letting X, X', and X'' represent the departures from these averages in any particular case, the standard deviations can be fitted reasonably well by the formulæ, $0.93 - 0.50X$ for litters per year, $3.19 + .13X'$ for young per year, and $2.57 + .05X''$ for young raised per year. The probable errors in Table 31 were calculated from the formulæ $PE = 0.6745 \frac{\sigma}{\sqrt{n}}$ where n is the number

of mating years (Table 14) and σ is calculated from the above formulæ, using the means in Table 14.

The formula for the probable error of a percentage (p) is 0.6745 $\sqrt{\frac{p\ (1-p)}{n}}$. In applying this to percentage born alive, the question arises as to whether n should be the number of individuals (in litters of 1 to 4) or the number of litters. In the former case $\sqrt{n}$ is about 50 per cent larger than in the latter. A compromise is in line with the system of indices which has been used. Accordingly, n has been taken as the number of individuals born in litters of 1 to 4, but the resulting estimate of the probable error has been increased by 25 per cent, i. e., $PE = 1.25 \times 0.6745 \sqrt{\frac{p\ (1-p)}{n}}$.

The percentage raised of the young born alive has been dealt with similarly, n being the number born alive in litters of 1 to 4. In the case of the percentage raised of all young, n is again the total number born in such litters.

Similar considerations apply in the case of the weights. The formula $PE = 1.25 \times 0.6745 \frac{\sigma}{\sqrt{n}}$ has been used in each case, n being the total number born in litters of 1 to 4 in the case of the birth weight of all young, and merely the number raised in such litters in the other cases. The standard deviations for a given size of litter have been taken as 14.76 grams for birth weight of all young, 13.62 grams for birth weight of young raised, 1.285 grams per day for gain, and 49.53 grams for 33 days' weight. These figures apply to litter means and follow from the following determinations based on an analysis of 3,009 litters of inbreds and controls:

Birth weight (total) ..... $\sigma_B' = 19.49$ grams.
$r_{BL} = -0.6580 \pm 0.066$.
${}_L\sigma_B' = 14.76$ grams.

Birth weight (raised) ..... $\sigma_B = 18.09$ grams.
$r_{BL} = -0.6580 \pm 0.066$.
${}_L\sigma_B = 13.62$ grams.

Gain ..... $\sigma_G = 45.87$ grams (33 days).
$r_{GL} = -0.3807 \pm 0.0105$.
${}_L\sigma_G = 42.42$ grams $= 1.285$ grams per day.

Weight at 33 days ..... $\sigma_{33} = 57.58$ grams.
$r_{BG} = +0.5326$.
${}_L\sigma_{33} = 49.53$ grams.

The formula for standard deviation for a given size of litter (L) is of the type

$$ {}_L\sigma_B = \sigma_B \sqrt{1 - r^2_{BL}}. $$

The formula for ${}_L\sigma_{33}$ is derived from the equation

$$ {}_L\sigma_{33}^2 = {}_L\sigma_B^2 + {}_L\sigma^2_G + 2\,{}_L\sigma_B \cdot {}_L\sigma_G \cdot {}_Lr_{BG}. $$

The probable errors derived from these formulæ are given in Table 31 for comparison with the values shown in Table 29, and the differences between experiments shown in Table 30. The probable errors of the differences are from 10 to 20 per cent larger than the figures shown.

Before closing the discussion of probable errors there is one other point which should be brought up. We have based the probable errors on the number of litters or on a compromise between number of litters and number of individuals designed to allow for the correlation between litter mates. But the characteristics with which we are dealing here are wholly or in part characteristics of the parents. Should we not therefore base the probable errors on the number of matings? We have, however, previously (Part I, Bulletin 1090) called attention to the fact that there is no significant correlation between the successive records of a given mating as to size of litter, interval between litters, birth weight, and gain (Experiment B). This can also safely be affirmed of the mortality among the young. Thus persistent good or poor health of the dam or sire can be of very little importance in determining these characters.

In most experiments the parents are either inbreds or first crosses between inbred families and thus should be homogeneous genetically. In these cases there would seem no question that the litter, if not the individual, is the proper unit in calculating probable errors of experiment averages. In the cases in which segregation should be taking place among the parents (C2, CL, CG, and B) the propriety of this course depends on the number of factors involved. If only one allelomorphic series of factors were involved in the differences among the families in a given respect, the testing of only a few second generation females in C2 might give very misleading results, whatever, the number of litters produced by each one. If, however, many factors are involved, as is probably the case, the genetic heterogeneity should be less. It is believed that a sufficient number of matings was made in all cases to make the parents a fair sample of their respective experiments. The number of matings which produced young is given for each experiment in Table 10.

RESULTS.

We have concluded that the differences between each experiment and the inbreds as shown in Table 2 give a satisfactory basis for comparison.

The same results are shown graphically in Figures 8 to 19. A general survey of the figures establishes beyond question that marked improvement in every respect is brought about by crossbreeding. The characters, however, fall into two rather sharply opposed categories. In some of them there is little or no improvement in the

first cross, though marked improvement in the next generation. The percentage born alive, birth weight, size of litter, and frequency of litters come here. In the cases of percentage raised of those born alive, and gain, there is on the other hand marked improvement in the first cross.

THE PERCENTAGE BORN ALIVE.

A number of points of interest are brought out in Figure 8 in reference to the mortality at birth. It is shown that there is considerable variation among the inbred families, but that no one of them has as good a record as the random-bred stock (B). There is only a slight improvement, too small to be relied upon, when two families are

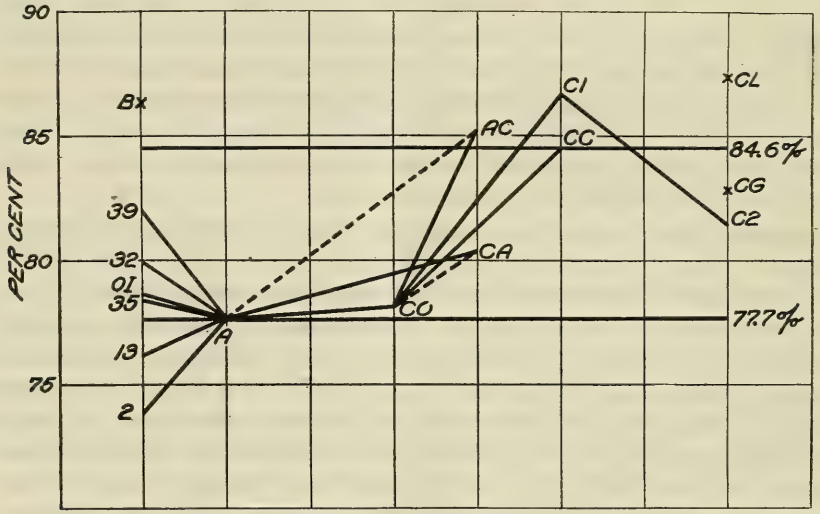

FIG. 8.—The percentage born alive, 1916–1919. Indices correcting for effects of size of litter and seasonal conditions: 2, 13, 32, 35, 39, inbred families; 0I, other inbred families; A, average of all inbreds; C0, first cross between inbred families; CA, crossbred male from C0, unrelated inbred female; AC, inbred male, unrelated crossbred female from C0; CC, crossbred male, unrelated crossbred female; C1, crossbred brother and sister from C0; C2, brother and sister from C1; CL, selection for large litters, small weight; CG, selection for small litters, large weight; B, random-bred stock.

crossed (C0). When, however, the crossbred females produce young, whether mated with an unrelated crossbred (CC), with a brother (C1), or with an unrelated inbred (AC), there is a substantial improvement which goes beyond the best of the inbred families and reaches practically the level of the random-bred stock. In contrast with the good record of Experiment AC is the relatively small improvement over the inbreds in the reciprocal cross CA, in which inbred females are mated with unrelated crossbred males. It is clear from these results that crossbreeding increases the number of young born alive, but that the breeding of the dam, not that of the young themselves, is the critical factor. The most significant line of cleavage between high and low records falls between Experiments A, C0, and

CA, in which inbred females are mated in various ways, and Experiments CC, C1, and AC, in which the females are crossbred. *A priori*, one might expect that the inherent vigor of the young would count for something, and the slight improvement in Experiments C0 and CA can be interpreted in this way. The superiority of C1 to CC, however, does not support this view. These experiments differ only in that the young of C1 are to some extent inbred. The superiority of CA over C0 might be interpreted as due to a direct influence of the vigor of the sire, but the similar superiority of AC over CC is opposed. All of these minor differences may, of course, be due to chance.

Turning to the other experiments, we find that C2 is intermediate between the group with inbred dams and the group with crossbred dams. This is to be expected, since in C2 the dams as well as the young are inbred, though not as much as the dams in A, C0, and CA. Theoretically, as will be brought out later, C2 should be just halfway between the inbreds and Experiment CC.

Experiments CL and CG have averages close to the other crossbreeding experiments. The superiority of CL over CG seems to be due merely to chance. Recalling that the mated animals in CG were exceptionally vigorous when weaned, while those in CL were only two-thirds as heavy and usually unthrifty in appearance, it must be concluded that the females completely recover from setbacks early in life as far as ability to bear young successfully is concerned. It may also be concluded that the superiority of Experiments AC, CC, and C1 over the inbreds is not due in the slightest to unconscious selection of relatively more thrifty animals in making the matings.

In this discussion we have been considering the indices, in which there is correction for the effect of size of litter. In Figure 20 Experiments C0, CC, C1, B, and the inbreds are compared, taking each size of litter separately. These experiments were in progress practically at the same time, so that it is not necessary to make a correction for seasonal effects. The inferiority of the inbred females (inbreds, C0) is clearly brought out. It also appears that this inferiority is most marked in the larger litters. Large litters are at only a slight disadvantage as compared with small ones in the case of crossbred dams, but have a markedly higher death rate than small litters in the case of inbred dams.

Summing up, the fate of the young at birth depends primarily on the breeding of the dam, as far as it is genetic at all. Crossbred females mated in any way are able to produce a distinctly larger percentage of living young than females of the best of the inbred families which entered into their composition. The inferiority of inbred females is greatest in large litters. About half of the superiority of the crossbreds is lost in the progeny of females from the first

generation of renewed inbreeding. The apparent thriftiness of the females in their early life gives no clue to their later success in bearing young.

THE PERCENTAGE RAISED AMONG THE YOUNG BORN ALIVE.

On comparing Figure 9 with Figure 8, which we have just been considering, the difference in the positions of Experiments C0 and CA at once attracts attention. In fact, as regards the percentage raised of the young born alive, every crossbreeding experiment is above the average of the best inbred families. It is clear that the breeding of the young is an important factor in the mortality between birth and weaning. The relatively advanced stage of development at which guinea pigs are born and their ability to care for themselves at a very

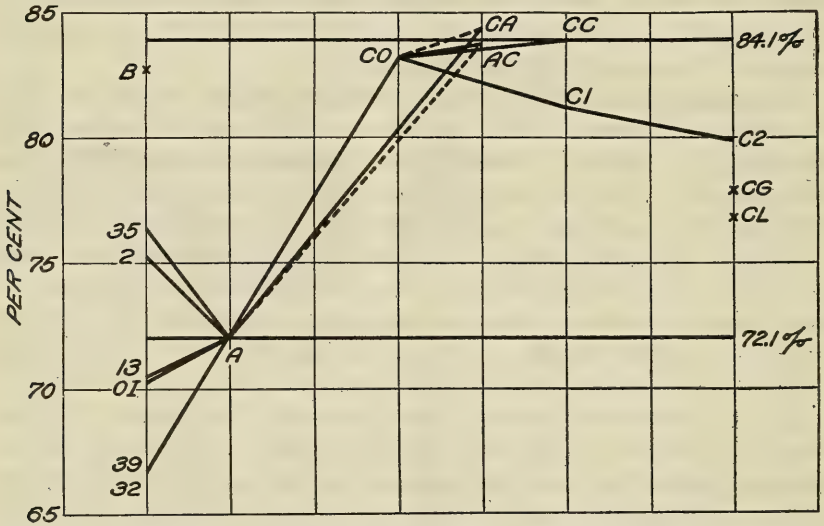

FIG. 9.—The percentage raised of the young born alive, 1916–1919. Indices correcting for effects of size of litter and seasonal condition. (See Fig. 8 for explanation of symbols.)

early age come to mind here. Experiment C0 is like the inbreeding experiments as regards breeding of sire and dam and also as regards the elimination of young at birth. The improvement of C0 over the inbreds shown in Figure 9 thus measures directly the effect of the crossbreeding of the young themselves. The level of random-bred stock is reached immediately. The record of Experiment CA, also inbred dam, crossbred young, is even higher. The fact that the records are no higher in Experiments CC and AC, in which the young are equally crossbred and the dam also is crossbred, might be taken as indicating that the breeding of the dam is of no importance whatever in the rearing of the young. This conclusion, however, is not really warranted by the data. It will be remembered that there was a distinctly heavier elimination at birth in Experiments C0 and CA

than in CC and AC. Thus the dams with living young in the former experiments were a more selected sample than those of the latter. It seems probable, then, that there really is a relation between the breeding of the dam and success in rearing the young, but that it is masked in the present case by an interrelation with the mortality at birth.

The records of the inbred families are interesting in this connection. There is considerable variation, which, as shown in the previous paper, is significant and persists from year to year. The two poorest families in rearing the young (39 and 32) were the two best in percentage alive at birth, while the poorest in the latter respect (2) is next to the best in rearing the young. There is here a suggestion of a negative interrelation ($r = -0.60$). It has been shown, however (part II, Bulletin 1090), that in two earlier periods when 23 families were on hand there was no significant correlation between the records in these two respects ($r = +0.03$ for 1906–1910 and $r = +0.30$, 1911–1915). As indicated in the above paper, we probably have an unstable balance between the influence of certain genetic factors which tend to bring about a positive correlation and the tendency toward a negative correlation due to the influence of selective mortality at birth on postnatal mortality.

The record of Experiment C1 is somewhat below that of CC. It is of course expected that a decline will be shown in the first generation of renewed inbreeding in a character in which the breeding of the young is a factor. If the breeding of the dam were of no importance at all, the record of C1 should be only half as much above the inbreds as CC. The relatively small decline of C1, especially in view of its unexpectedly high record in percentage born alive, is thus evidence that the breeding of the dam does count. There is a further decline in Experiment C2, where both parents and young are inbred. As will be explained later, the record of C2, whether due to dam or young or both, should be just halfway between the inbreds and CC.

The records of CG and CL are somewhat lower than expected but still above the best of the inbred families. Here again it is shown that the condition of young at weaning gives no indication of their success later as parents.

The mortality between birth and weaning is shown separately for each size of litter in Figure 21. The results agree with those obtained from the use of indices.

Summing up, the mortality between birth and weaning depends primarily on the characteristics of the dam. A much larger percentage are raised among crossbreds in all sizes of litter than in the best of the inbred families. The apparent thriftiness of the parents when they themselves were weaned gives no indication of the mortality to be expected among their young.

THE PERCENTAGE RAISED OF ALL YOUNG BORN.

The percentage raised of all young born is simply the product of the two which we have been considering. Figure 10 brings out the superiority of crossbred young from inbred dams (CO, CA) over inbreds, and the still greater superiority of crossbred young from crossbred dams (AC, CC). The record of the first generation inbreds from crossbred dams (C1) is a little higher than theory would indicate. There is, however, a decline in the next generation of renewed inbreeding (C2) of almost the expected amount. It is noteworthy that the record of the random-bred stock (B) is practically reached by crossbreeding involving only three or four of the inbred families.

One of the most striking results is the great advance of the crossbreds over the best of the inbred families. The superiority of the best inbred family over the average is increased more than fourfold.

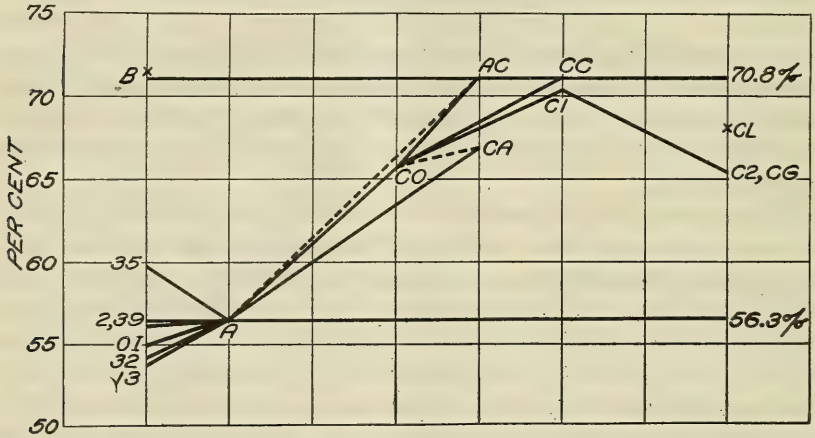

FIG. 10.—The percentage raised to 33 days of all young born, 1916–1919. Indices correcting for effects of size of litter and seasonal conditions. (See Fig. 8 for explanation of symbols.)

This is a much greater relative increase than shown in the case of either component percentage. The reason is easily discovered. An inbred family which is above the average in percentage born alive is perhaps more likely than not to be below the average in the percentage of these raised. It thus comes about that there is no more differentiation among the families in the total percentage raised than in either component. The second generation crossbreds, on the other hand, are superior in both components and thus very much superior in the product. We have here a good illustration of the way in which a great superiority of a crossbred stock over the best of its ancestral inbred families with respect to a complex character may be built up out of mere dominance of vigor over weakness in a number of more elementary characters which are distributed at random among the inbred families. Further illustration of this point will be taken up later.

BIRTH WEIGHT.

Figure 11 shows how the various experiments compare with respect to birth weight. On the whole there is considerable similarity to the situation with respect to percentage born alive (Fig. 8). In both cases the records of inbred females, however mated (inbreds, C0, CA) are poor compared with those of crossbred females (AC, CC, C1). Again there is a marked decline in both cases in the second generation of renewed inbreeding.

This similarity may be due in part to a direct causal relation. Stillborn young are naturally considerably lighter than young born alive. The high birth weights of the progeny of crossbred dams might thus be due merely to their relatively small percentage of stillborn young. This complication is avoided by comparing the birth weights of only those young which reach 33 days (Fig. 12). We find, in fact, that

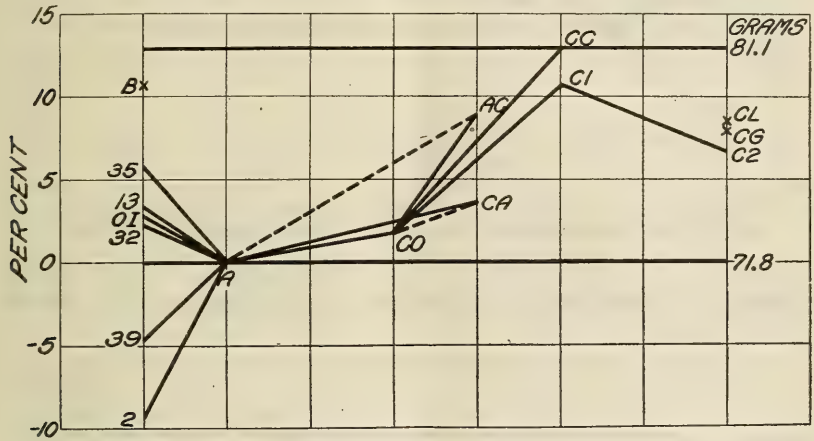

FIG. 11.—The birth weight of all young born, 1916–1919. Indices correcting for effects of size of litter and seasonal conditions (Table 2). (See Fig. 8 for explanation of symbols.)

the differences among the experiments are reduced. Nevertheless the essential points noted above are still present. It seems clear that the prenatal rate of growth depends largely on the characteristics of the dam as far as it depends on heredity at all. The heredity of the young, however, seems to be more important than in the case of the percentage born alive, as indicated by the records of Experiments C0 and CA in comparison with the inbreds. That the agreement in the standing of the crossbreeding experiments in relation to the total inbreds in the two respects, birth weight and percentage born alive, does not rest on a common physiological factor is shown by the lack of agreement among the separate inbred families.

Experiment CG, in which the parents were selected because of their exceptionally great weight at weaning, produced heavier young than Experiment CL, in which the parents were underweight at the same age. Even CL, however, is well above the average of the inbreds

while CG is no better than the second generation crossbreds. It is not safe to conclude that the selection for weight has had any effect.

The birth weights of the young raised in the inbred families and in Experiments C0, CC, C1, and B are compared for each size of litter

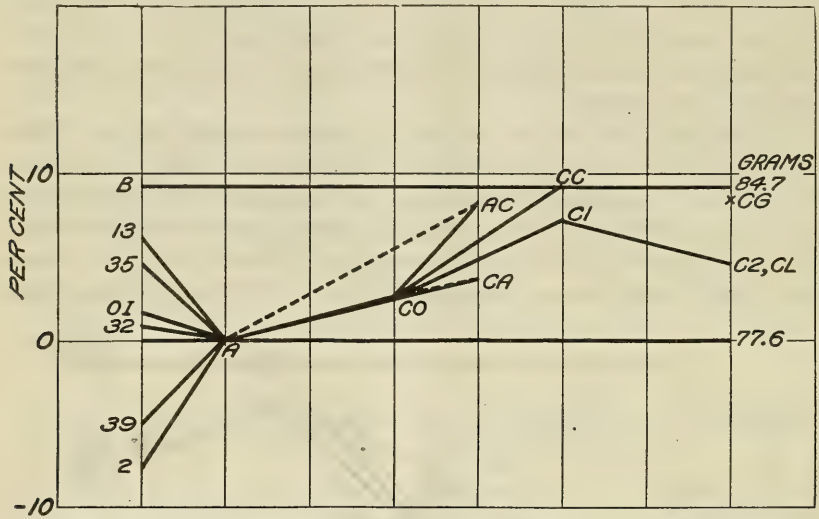

FIG. 12.—The birth weight of the young raised to 33 days, 1916–1919. Indices correcting for effects of size of litter and seasonal conditions (Table 2). (See Fig. 8 for explanation of symbols.)

in Figure 22. The great effect of size of litter on birth weight is illustrated. Otherwise the conclusions are the same as those drawn from the indices.

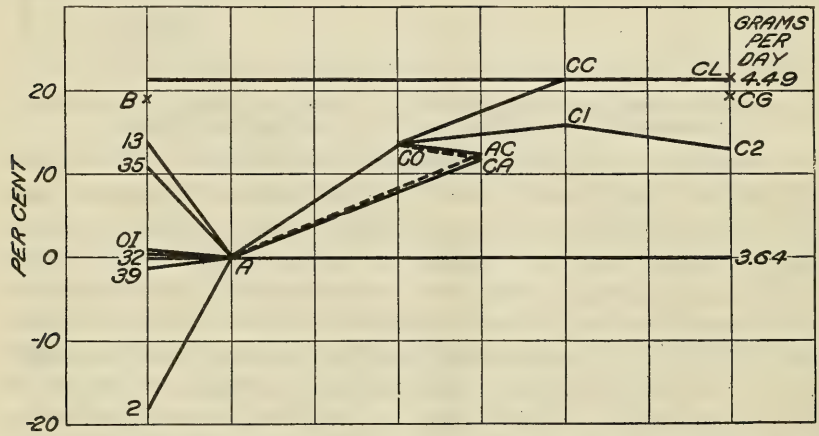

FIG. 13.—The rate of gain between birth and 33 days, 1916–1919. Indices correcting for effects of size of litter and seasonal conditions (Table 2). (See Fig. 8 for explanation of symbols.)

DAILY GAINS.

We have seen that the results for birth weight are similar to those for percentage born alive. The results for daily gain between birth and weaning (Fig. 13) are, on the other hand, more like those for

percentage raised of the young born alive. The superiority of the crossbreds produced by inbred females (C0, CA) over inbreds shows that the heredity of the young counts for a great deal. The still greater superiority of the crossbreds from crossbred parents (CC) shows, however, that the breeding of the dam is also of much importance, as would of course be expected. The effects of renewed inbreeding may be seen in the lower average of C1 as compared with CC and the still lower average of C2. The result of crossing inbred male with crossbred female (AC) is practically the same as the reciprocal cross (CA). One would expect an average as high as CC. There seems to be no explanation other than an extreme chance deviation.

The young from crossbreds selected for their rapid gains (CG) did not show as great a percentage advance over the inbreds as the young

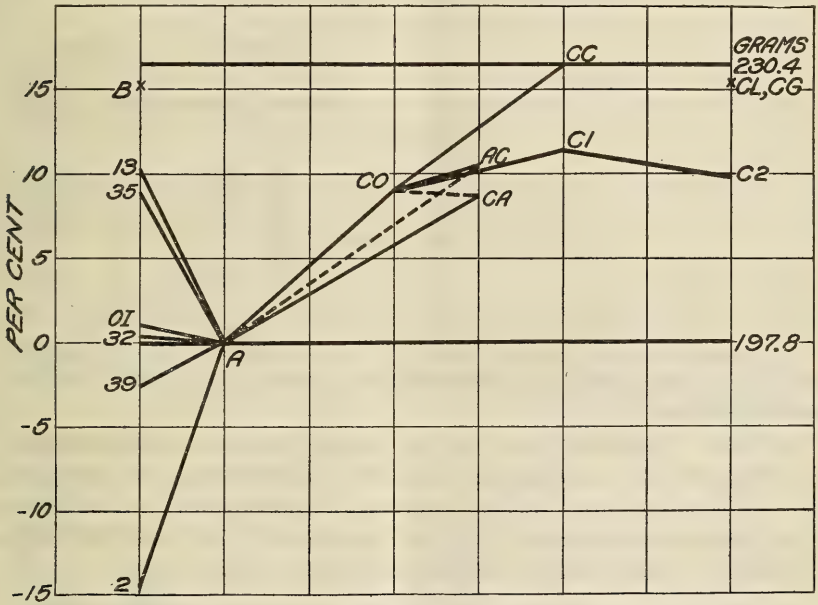

FIG. 14.—The weight at 33 days, 1916–1919. Indices correcting for effects of size of litter and seasonal conditions (Table 2). (See Fig. 8 for explanation of symbols.)

from the subnormal parents in Experiment CL. We again conclude that direct selection is futile in the case of characters of the kind dealt with here, in which hereditary differences are small compared with those due to environment.

The comparison of the gains of the inbreds C0, CC, C1, and B in separate sizes of litter (Fig. 23) confirms the results from the indices.

WEIGHT AT WEANING.

This is merely the sum of the birth weight of the young raised and the gain from birth to 33 days (Fig. 14). As it depends largely on the latter factor, no additional points of interest are brought out.

ADULT WEIGHT.

The complete growth curve has been studied in those animals which have been saved beyond 33 days. The details will not be discussed in the present paper. It may be said, however, that a pronounced effect of crossbreeding is observable in the first generation of crossing and that about half of the increase is lost in the first generation of renewed inbreeding.

Table 8 shows the average weights of males and females in the five large inbred families and in the random-bred stock, 1916 to 1919 inclusive, taken at the time of recording a litter at the ages of 12 or 13 months. The females are thus not pregnant.

TABLE 8.—*Average weights at 12 or 13 months (1916–1919); taken after birth of litter, inbreeding experiments and random-bred stocks.*

Family.	Males.		Females.	
	Number.	Weight (grams).	Number.	Weight (grams).
2	36	716± 6.9	35	625± 5.3
13	31	845± 9.2	33	686±11.1
32	20	700±10.1	21	649± 7.8
35	32	770±10.4	32	669± 8.6
39	16	757±17.0	14	653±19.1
Total inbred	135	761± 5.4	135	657± 4.5
B	58	852± 9.9	60	700± 7.9

The superiority of the males over the females, of the crossbreds over the inbreds, and the differentiation among the inbred families, are brought out.

In Table 9 animals from the first cross between inbred families, and from the first generation of renewed inbreeding, are compared with the inbreds used in crossbreeding experiments. As in Table 8, the weights were taken at 12 or 13 months of age after the birth of a litter. These inbreds are not included in Table 8.

TABLE 9.—*Average weights at 12 or 13 months (1917–1920); taken after birth of litter. Animals used in crossbreeding experiments.*

Experiment.	Males.		Females.	
	Number.	Weight (grams).	Number.	Weight (grams).
Inbreds (in CO, AC, CA)	95	776 ± 6.4	91	641 ± 4.8
CO (in CC, C1, CA, AC)	77	865 ± 8.8	82	726 ± 6.6
C1 (in C2)	9	824 ±13.2	9	667 ±17.5

It will be seen that the first cross (CO) results in an increase of 12 or 13 per cent in adult weight, but that at least half of this is lost

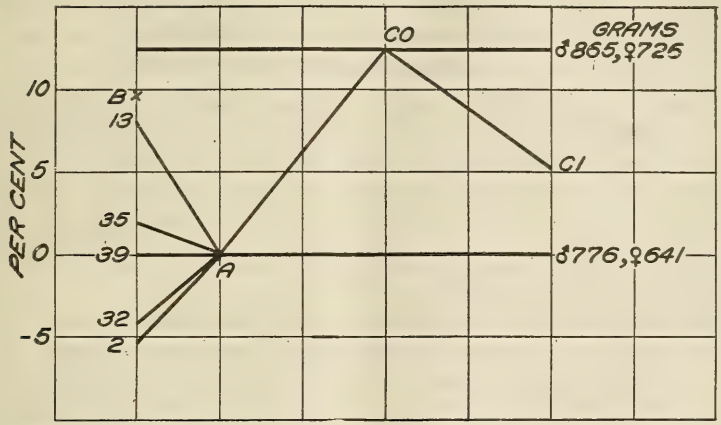

FIG. 15.—Adult weight, 1917–1920. Comparison between inbred families (2, 13, 32, 35, 39), total inbreds (A), random-bred stock (B), first cross (C0), and first generation of renewed inbreeding (C1). Percentage differences for males and females averaged. (See Table 9.)

on renewing inbreeding (C1). Figure 15 brings out these points graphically.

FREQUENCY OF LITTERS.

It is conceivable that the heredity of the fetuses might make a difference in the number of litters completely absorbed or aborted at

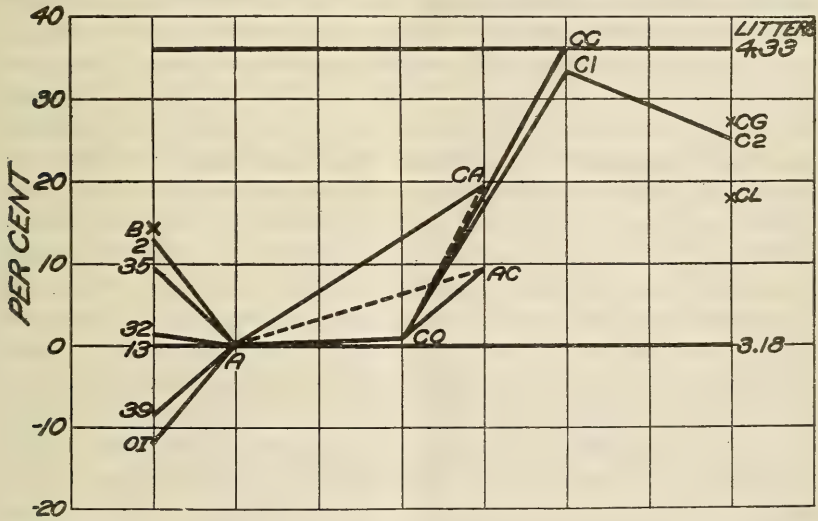

FIG. 16.—Regularity in producing litters (litters per mating per year), 1916–1919. Effects of seasonal conditions eliminated (Table 2). (See Fig. 8 for explanation of symbols.)

an early stage, and thus make a difference in the frequency of recorded litters. As it turns out, however, the frequency of litter (Fig. 16) is

virtually identical in the cases of inbred females mated respectively with brothers (young inbred) and with unrelated inbred males (C0).

When the crossbred young themselves become parents there is a marked increase in the regularity with which litters appear. The result is practically the same whether these crossbred parents are unrelated (CC) or brother and sister (C1), again indicating that the vigor or weakness of the young is not a factor. A falling off appears when the parents are from the first generation of renewed inbreeding (C2). In these respects there is considerable similarity in the results shown in Figures 8 and 12, dealing with percentage born alive and birth weight, respectively, characters which we concluded were largely dependent on the dam.

There is, however, a striking contrast with those cases in the standing of Experiments CA and AC. The great increase in frequency of litter when a crossbred male instead of an inbred is mated with an inbred female (CA) seems to mean that the sire is most apt to be responsible for irregularity in producing litters. The mating of inbred males with crossbred females (AC) however gives a better record than where both parents are inbred. This indicates that the female is also responsible to some extent. The still greater improvement where both parents are crossbred (CC, C1) substantiates further the responsibility of both parents.

It should be recalled here, however, that Experiments CA and AC are compared with inbreds during a period when the latter were producing litters more frequently than the inbreds breeding simultaneously with CC and C1. The actual records of AC and CA were only slightly below CC and C1 and were so near the upper limit possible for a guinea pig (which is about 5.3 litters per year) that the superiority of CC and C1 over CA and AC is probably somewhat exaggerated in Figure 16. The same considerations apply to Experiments CG and CL, which would probably have made records more nearly like CC and C1 under strictly comparable conditions. The main conclusion that frequency of litter depends primarily on the sire and secondarily on the dam is not weakened.

Another important result is the great superiority of crossbreds derived from only two inbred families over the random-bred stock. In the other characters with which we are dealing there is merely a recovery of the condition of the latter. It is probably not a coincidence that frequency of litter is the only one of our characters in which the miscellaneous inbred families (OI) are inferior to the five largest families (2, 13, 32, 35, and 39). It seems probable that regularity in producing litters has been the most important factor in the unconscious natural selection among the inbred families and that the crossbreds are in this case derived from a selected ancestry. The possibility of improvement in all characters through conscious

selection from a group of inbred lines, followed by crossbreeding, is clearly indicated. The method is especially applicable to characters such as those used here, in which heredity is such an insignificant factor in individual cases that selection of individuals is of no value.

AGE OF MATURITY.

It was thought at first that the influence of the sire on frequency of litter as here measured might be due to earlier maturity of crossbred males. Females, as noted previously, may become capable of reproduction at one month of age, while males only begin to mature at about two months. If crossbred males mated at weaning were able to produce a litter in advance of the inbred males, they would produce more litters in the first year of mating even though there were no greater regularity after their first litter. However, a tabulation of the ages of the males at birth of their first litters (Table 10) shows that earlier maturity of the males does not explain the superiority of CA over AC. Their first litters were produced at nearly the same age, (5.09 and 5.03 months). The superiority of all crossbreeding experiments (except C0) over the inbreds seems, however, to be in part explained by earlier maturity of the parents.

TABLE 10.—*Average age of males, mated when 1 or 2 months of age, at birth of their first litter, and average interval from mating to first litter in case of males 3 months old or over when mated. First litters born 1916–1919.*

Experiment.	Male mated at 1 month.		Male mated at 2 months.		Male 3 months or over.	
	Number.	Average age at first litter.	Number.	Average age at first litter.	Number.	Average interval to first litter.
2	62	5.84	1	5.00	5	3.20
13	55	5.80	0	.....	2	3.00
32	40	5.78	1	5.00	3	4.00
35	76	5.40	0	.....	2	5.50
39	25	6.28	0	.....	6	4.50
Other	84	6.18	0	.....	0	.....
Inbred	342	5.85	2	5.00	18	4.00
C0	94	5.73	33	6.06	30	4.17
CA	35	5.09	4	5.50	3	4.33
AC	30	5.03	7	5.43	9	3.67
CC	20	4.90	20	5.40	4	3.50
C1	46	5.09	5	5.80	0	.....
C2	17	4.77	2	5.00	0	.....
CL	29	5.21	6	5.17	4	3.25
CG	40	4.68	10	5.20	0	.....
B	20	5.05	29	5.48	48	4.23

Apparently the females, which were in all cases of practically the same age as the males at the first litter, were also in part responsible for the delay in the first litter of inbreds. The relatively early age of first litter in AC proves this.

One interesting side light is the remarkably early average age at first litter in Experiment CG (4.68 months) and the greater age in CL (5.21 months) as compared with most of the other crossbreeding experiments. We have here the clearest case of a difference between these experiments due to selection. The unusually heavy animals

in CG produced a litter two weeks earlier than the small-sized animals of CL selected because of birth in a large litter.

An unexpected result is shown in the last column in the long interval between mating and first litter when the animals were already 3 months or more of age at mating. Compare especially the age of 5.05 months at which weanlings in Experiment B produced their first litter with the interval of 4.23 months between mating and first litter in the case of parents already mature at the time of mating.

COMPLETE STERILITY.

There has not been much complete sterility in any stock, inbred or crossbred. Among 335 matings of inbreds which were kept for at least one year after maturity, only six failed to produce young. Three of these were kept through a second full year and continued sterile. Two of them belonged to Family 36, one to Family 17, while the other three were in Experiment C0, two being matings

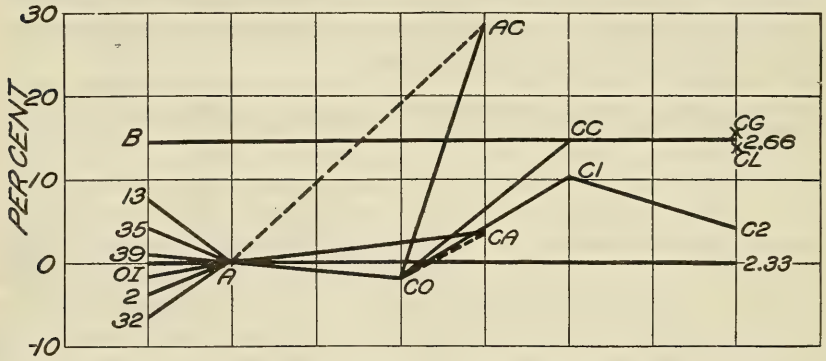

FIG. 17.—Average size of litter, 1916–1919. Effects of seasonal conditions eliminated (Table 2). (See Fig. 8 for explanation of symbols.)

between a male of 38 and a female of 13 and the other between a male of 39 and a female of 32. Among 234 matings in which one or both of the parents were crossbred and which were kept for more than 12 months, only two failed to produce young.

SIZE OF LITTER.

In the study of the size of litters the heredity of the young is again shown to be of no account by the comparison (Fig. 17) between the inbreds and the first cross (C0). The superiority of Experiment CA over C0 is so slight ($1.5 \times PE$) that it can not be taken as evidence that crossbreeding of the sire has any influence on size of litter.

The reciprocal cross, inbred male by crossbred female, however, gives such a great increase that there can be no question about the effect of crossbreeding of the dam on her fecundity.

The effect of crossbreeding of one of the parents, presumably the dam, is shown by the records of Experiments CC and C1. But the

fact that these experiments gave very much less increase than AC confronts us with something of a puzzle. The difference is too great to be dismissed as due to chance ($5.8 \times PE$). The probable explanation is a reciprocal physiological relation between frequency and size of litter. It has, in fact, been found in the inbred stock that when one litter follows immediately after another (i. e., in 9 or 10 weeks, the gestation period), it is smaller than the average, and that a large litter predisposes toward a delay before the appearance of the next litter. (See Part I, Bulletin 1090.) These negative relations were not very strong, and in the more vigorous random-bred stock the relations were positive. We doubtless have, however, as suggested in the case of the relations between mortality at birth and mortality between birth and weaning, an unstable balance between opposed influences. It was shown in Part I that the records of the inbred and control stocks rose and fell in parallelism from year to year in these two elements of fertility (as well as in all other elements of vigor). In the present paper it is shown that there is considerable agreement between frequency and size of litter in the rise and fall from season to season during 1916 to 1919 (Figs. 4 and 5). Thus external conditions tend to produce a positive correlation. There may also be common genetic factors which tend the same way. The apparent conflict between the evidence from random-bred and inbred stocks, referred to above, merely means that in the random-bred stock the causes of positive correlation were not completely balanced by the reciprocal physiological relation suggested above, while it was overbalanced in the inbred stock. One would expect to find the physiological relations more important in the weaker inbred stock.

In comparing AC with CC or C1 we have experiments in which the inherent characters of the dam and young are essentially the same. Owing, as it appears, to the influence of the crossbred sire, CC and C1 produced litters distinctly more regularly than did AC. We have here a situation in which a negative physiological correlation could reveal itself uncomplicated by any positive correlation. The high record of AC relative to CC and C1 in size of litter and the opposite relations in frequency of litter are the expected results on this hypothesis.

Similarly the relatively high record of CA in frequency of litter may exert a slight depressing influence on its record in size of litter. The argument that the sire exerts some influence on size of litter is strengthened, but hardly enough to be relied upon.

We may conclude that crossbreeding causes a marked increase in the size of litters produced by females. Crossbreeding of the sire may have some influence, but too slight to be demonstrated by the present data. The heredity of the young appears to be wholly without influence. It may be added that selection of the dams (and

sires) from large litters (CL) or from small litters (CG) is without effect.

TOTAL FERTILITY.

The number of young born per mating year (Fig. 18) is merely the product of the two elements of fertility, frequency and size of litter,

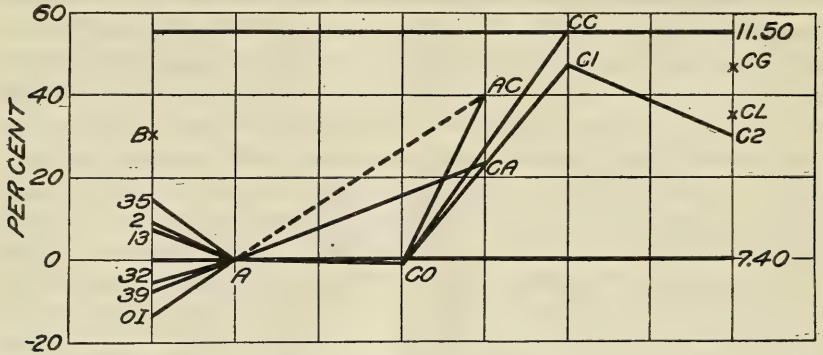

FIG. 18.—Young per mating per year, 1916–1919. Effects of seasonal conditions eliminated (Table 2). (See Fig. 8 for explanation of symbols.)

which we have discussed separately. It is interesting to find that the dam has more influence on total fertility than the sire, in spite of the greater influence of the latter on frequency of litter. Selection

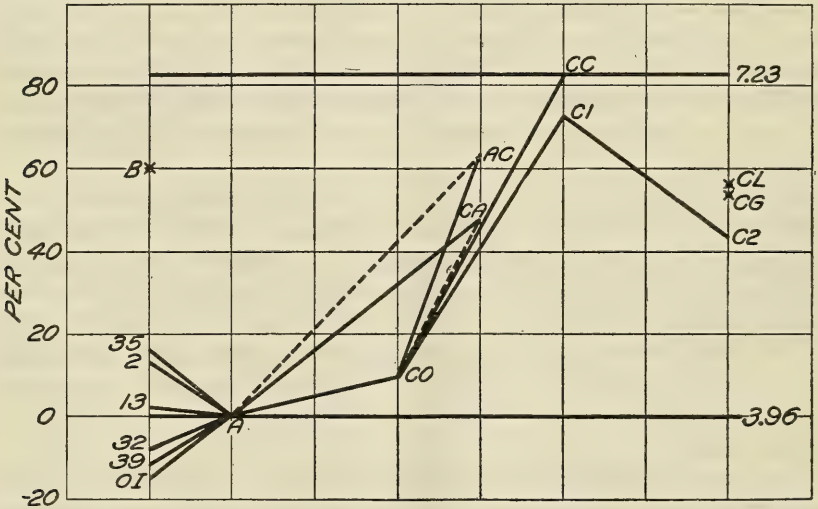

FIG. 19.—Young raised per mating per year, 1916–1919. Effects of seasonal conditions eliminated (Table 2). (See Fig. 8 for explanation of symbols.)

of parents on the basis of size of litter is shown to be wholly without effect.

The best single measure which we have of the reproductive efficiency of the experiments is the number of young raised per year. This is the product of the young born per year and the percentage raised to 33 days (actual, not index). Figure 19 shows the tremendous advance

(more than 80 per cent) obtained in the second generation of crossbreeding over the average of the inbred families. The record of the original random-bred stock is surpassed by nearly 15 per cent by

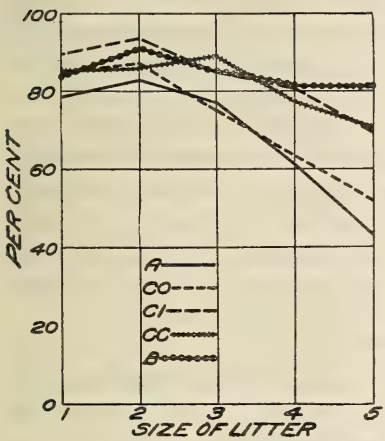

FIG. 20.—The percentage born alive, by size of litter (Table 15), 1916–1919. (See Fig. 8 for explanation of symbols.)

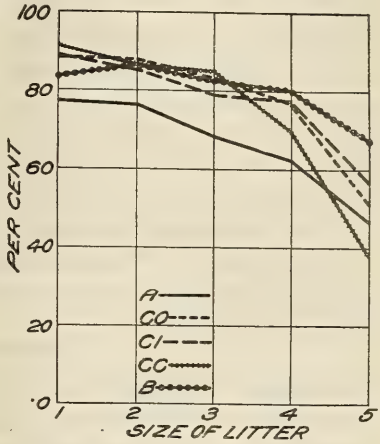

FIG. 21.—The percentage raised of the young born alive, by size of litter (Table 16), 1916–1919. (See Fig. 8 for explanation of symbols.)

Experiment CC. In fact, it was merely necessary to cross two inbred families and obtain a second generation (C1) to obtain an advance of 70 per cent over the inbred ancestry and go beyond the random-bred stock.

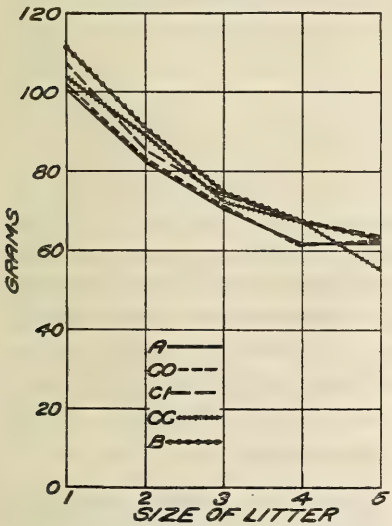

FIG. 22.—The birth weight of young raised to 33 days, by size of litter (Table 19), 1916–1919. (See Fig. 8 for explanation of symbols.)

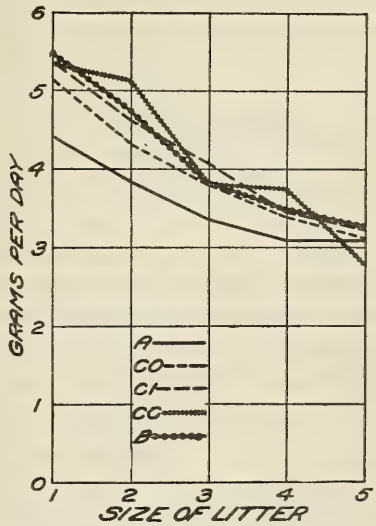

FIG. 23.—The rate of gain per day by size of litter (Table 20), 1916–1919. (See Fig. 8 for explanation of symbols.)

Another important result is seen in comparing the advance of 80 per cent in Experiment CC with the 16 per cent by which the best inbred family differs from the average. Looking at this result alone,

it seems difficult to believe that the superioity of the crossbreds is due merely to dominance of factors present in some of the inbred families, but absent in others, the hypothesis which will be at the basis of our later discussion. We are, however, able to analyze the character which we are considering into four components. The crossbreds do not exceed the best inbred family to anything like as great an extent in each of these component characters. The superiority of the crossbreds is consistent, however, and hence cumulative, in comparison with the superiority of the best inbred family over the average, the "best" inbred family being one family in one case and another in another. The four component characters are themselves doubtless highly complex genetically. If further analysis were possible, it might well turn out that dominance of the factors tending toward vigor in each respect is not even perfect.

COAT COLOR.

Six series of Mendelian factors are known which affect color in guinea pigs. Among our five leading inbred families there are variations in only two of these series, the albino series (C, c^k, c^d, c^r, c^a) and the agouti series (A, a', a). All five families are piebald (s) instead of self (S), tortoise shell (e′) instead of self-black (E) or self-red (e), black (B) instead of brown (b), and black (P) instead of pink-eyed pale sepia (p).

TABLE 11.—*Color pattern and factorial composition of the five principal inbred families.*

Family.	Color.	Factorial composition.
2	Black-red-white tricolor	CCaa.
13	Black-red-white tricolor	CCaa.
	Occasional albinos	c^ac^aaa.
32	Agouti-red-white tricolor	CCAA.
35	Yellow agouti-yellow-white tricolor	c^kc^kAA.
39	Agouti-red-white tricolor	CCAA.

First crosses between Families 2 and 13 produce black-red-white tricolors. All other first crosses among these five families produce agouti-red-white tricolors, except that occasionally cream agouti-cream-white tricolors (c^kc^aAa) appear in crosses between Families 35 and 13. Segregation takes place in regular Mendelian fashion in later generations, there being no linkage between factors C and A.

RESISTANCE TO TUBERCULOSIS.

Experiments conducted cooperatively by the Bureau of Animal Industry and Dr. Paul A. Lewis, of the Henry Phipps Institute, have been described in another paper (Wright and Lewis, 1921).

It was found that there was very little relation between age, weight, rate of gain, or sex, and the length of life after inoculation with tuberculosis. These factors combined determined less than 7 per cent of the variation in a very heterogeneous lot.

On the other hand, marked differences were found among the inbred families. Family 35, the most resistant, lived about twice as long after inoculation, on the average, as the poorest family, No. 39. Family 2 is second in resistance, Family 32 third, and Family 13 fourth.

Families 35 and 2 are superior to the random-bred stock B in this respect.

Crosses between families produce young which are in general at least as resistant as the better parent family. In particular cases the young are distinctly more resistant than either parent family. There is thus dominance of resistance over susceptibility and in particular cases each parental family supplies something lacking in the other.

Comparisons between Experiments CO, CA, and AC indicate that the full effect of crossbreeding is manifest in the first generation. The degree of resistance is determined by the genetic composition of the animal itself, the sire or dam being without direct influence.

EARLY VIEWS ON INBREEDING.

The general character of the results which have been obtained in the present experiments have little novelty. Inbreeding has been practiced by innumerable livestock breeders, in some cases merely because it was the path of least resistance, in other cases deliberately.

The great majority of these breeders, even those of the second class, have undoubtedly seen something like the degeneration described in the present paper—reduced size, lowered fertility, and increased difficulty in raising the young. In many cases much more serious degeneration has been encountered and the inbred line has rapidly become extinct. Conversely, the beneficial effects of outcrossing have often been observed. The popularity of the Angus-Shorthorn cross in Scotland threatened at one time to wipe out the pure Angus breed.

On the other hand, the use of inbreeding was an essential element in the success of the noted breeders, who laid the foundations of the modern pure breeds of livestock. It was to a large extent by inbreeding from carefully selected animals that they fixed the type which they desired and made it prepotent. This effect as well as degeneration finds its parallel in our experiments. We may call attention here to the unconscious fixation of color and to the isolation of important genetic differences in characters, such as weight and fertility, in which the degree of determination by heredity is too small to furnish a handle for direct selection.

Breeders thus have obtained sufficiently definite consequences following inbreeding. The question as to the effects has remained

unsettled, however, because those observed by different breeders seemed irreconcilable. There were two main theories among breeders. According to one, inbreeding has a specific detrimental effect, depending on its closeness and the length of time it is pursued, while the introduction of outside blood has a specific stimulating effect. According to the other view, inbreeding merely concentrates and intensifies the peculiarities of the given line, whether good, bad, or indifferent.

Neither of these theories was wholly satisfactory, the first because it failed to account for the success of such men as Bakewell, the Colling Brothers, Bates, Hewer, Cruickshank, and other noted breeders who practiced inbreeding; the second because it did not explain satisfactority the deterioration usually found on inbreeding a stock which appeared to combine every element of vigor.

PRE-MENDELIAN EXPERIMENTS.

The first systematic experiments on the subject were made by Darwin, who tested the effects of self-fertilization and crossing on a large number of plants. His results were closely similar in almost every respect to those which we have found on inbreeding guinea pigs. There was a similar degeneration in size, fertility, and vitality in most cases in which plants were used which are normally cross-pollinating. This degeneration did not continue indefinitely. Moreover, in some lines of a given species there would be little if any degeneration after many generations of selfing, while other lines of the same species degenerated rapidly. Crossing within a selfed line had no effect, but crosses between different lines resulted in increased vigor.

These results, the explanation of which seems clear enough to us to-day, were in some respects a puzzle to Darwin. He admitted that he was unable to formulate any complete explanation. He inclined toward the view that the degree of difference in the composition of the uniting germ cells has a specific stimulating effect. The following quotation expresses this view:

> There are two other important conclusions which may be deduced from my observations; firstly, that the advantages of cross fertilization do not follow from some mysterious virtue in the mere union of two distinct individuals, but from such individuals having been subject during previous generations to different conditions, or to their having varied in the manner commonly called spontaneous, so that in either case their sexual elements have been in some degrees differentiated. And secondly, that the injury from self-fertilization follows from the want of such differentiation in the sexual elements. These two propositions are fully established by my experiments.—(The effects of cross and self fertilization in the vegetable kingdom. London, 1876, p. 443.)

No fault is to be found with Darwin's experiments. That he was unable to formulate a thoroughgoing explanation of them was due

simply to the impossibility of such a formulation until more was known of the principles of ordinary heredity.

This same remark applies to a number of experiments on inbreeding of animals which were made before the rediscovery of Mendel's law. Crampe (1883) and Ritzema-Bos (1894) inbred rats and obtained marked degeneration in fertility and vitality. In Crampe's strain there was also considerable decline in weight and many abnormalities appeared, effects which Ritzema-Bos did not obtain. Weismann and Von Guaita bred mice brother and sister for many generations and noted a decline in fertility. Similar results were obtained by Fabre-Domengue with pigeons.

MENDELIAN HEREDITY AND THE PROBLEM OF INBREEDING.

With the rediscovery of Mendel's law, the explanation of at least one class of effects attributed to inbreeding at once became clear. It had often been noted that in the human race certain rare abnormalities, of which albinism is a good example, most frequently appeared among the progeny of consanguineous marriages. Good reasons were soon found for believing that albinism in man is a simple Mendelian recessive. A recessive factor can come into bodily expression only if it is received from both parents. A rare recessive trait is transmitted by many more people than actually show it. Nevertheless, these transmitters are relatively uncommon in the total population and the chances of union between them are not great. If, however, a given individual can transmit the trait, the chances are by no means small that a close relative will also have received the factor from the common ancestor and be a transmitter. Thus it is clear why consanguineous matings should frequently bring to light such traits as albinism. We see that inbreeding can not cause abnormalities of this kind to appear in a stock from which the genetic basis is absent. It is, however, a system of mating which is likely to reveal any abnormalities carried out of sight in the stock by recessive factors. We can see how inbreeding could lead to the frequent appearance of abnormalities in Crampe's stock of rats and yet fail to do so in the stock of Ritzema-Bos.

Castle and students (1906) inbred the fruit fly *Drosophila melanogaster* for 59 generations of brother-sister mating. While much sterility and low fertility appeared in the early generations, it was found possible to maintain high fertility by selection of lines. The segregation of recessive factors for low fertility was clearly indicated. These results have been confirmed as far as the main features are concerned in later experiments with the same fly by Moenckhaus, Hyde, and Wentworth.

Davenport (1908) called attention to the fact that in most known cases the dominant character in a pair of Mendelian allelomorphs was

the progressive one, while the recessive was retrogressive and often lacking in vigor. He pointed out that such a relation helped in understanding the degeneration sometimes but not always associated with inbreeding. This is very close to our present view. At that time, however, it was somewhat lacking in substance as a general explanation of the effects of inbreeding. The earlier work on Mendelian inheritance had naturally been confined for the most part to big, discontinuous variations. Thus the light which the Mendelian mechanism throws on the appearance of abnormalities following inbreeding was, as above stated, quickly recognized. It was not clear at first that any light was thrown on the relatively slight decline in size, fertility, and constitutional vigor which are more typical consequences of inbreeding. It was necessary to reach the viewpoint that hereditary differences may be due to a summation of the effects of numerous individually insignificant Mendelian units and that, indeed, the Mendelian mechanism is the universal mechanism of heredity under sexual reproduction.

The independent experiments of G. H. Shull and East with corn marked a big advance in adding substance to the general theory of heredity along the lines indicated above, as well as to the problem of inbreeding. Shull found that on self-fertilization an ordinary, seemingly homogeneous variety of corn broke up into strains, each highly uniform and differentiated from the others in numerous minute characteristics. There was more or less decline in size and productivity in all strains in the earlier generations of selfing, but stability was soon reached. On crossing these strains with one another there was in general a return to the original vigor.

All of these things had been observed by Darwin. On the basis of the new knowledge of heredity, however, Shull was able to show how everything could be explained on the assumption that an ordinary variety of maize is really a complex hybrid and that self-fertilization automatically isolates the various pure biotypes or "elementary species" through the segregation of Mendelian homozygotes, with the help of the additional assumption that the hybrids are more vigorous than the pure strains.

East obtained the same results and independently reached essentially the same conclusions. He suggested that there was a physiological stimulus to development in proportion to the degree of difference between the uniting germ plasms. This means in proportion to the amount of heterozygosis in some or all of the factors.

This view was contrasted with the older hypothesis which soon after was brought up again by Bruce and by Keeble and Pellew, that the vigor of crossbreds is due to dominance of factors conducive to vigor. Keeble and Pellew described experiments in which a cross between two pure strains of the pea produced hybrids taller than either, while

the segregation in the second generation proved that each strain furnished a dominant factor lacking in the other. In this case the factors were visibly different in effect, in that one increased the number of internodes, the other their length.

The two hypotheses are not easy to distinguish. Under both of them the departure from the condition of the pure inbred strains is in direct proportion to the amount of heterozygosis in at least certain factors. Under the stimulation hypothesis, however, the differences in vigor may be due to factors which of themselves have nothing to do with vigor: i. e., there may be no difference between AA and aa in vigor, while Aa may be superior to both. Under the dominance hypothesis it is merely to be supposed that Aa is equal to the more vigorous of the two homozygous types. Dominance indeed need not be perfect.

Under the dominance hypothesis it should be possible to isolate inbred strains, homozygous in all factors conducive to vigor and hence equal or superior to crossbreds. This should not be the case with the stimulation hypothesis. Again, under the dominance hypothesis, the crossing of two inbred strains, followed by random breeding, should result in a population with a skew distribution as regards measurable characters, according to the expansion of $(\frac{3}{4}+\frac{1}{4})^n$ where n is the number of factors. The distribution would be symmetrical under the stimulation hypothesis.

The invariable degeneration following self-fertilization which East observed in corn, and the failure to find skew distributions as the rule in the second generation of crosses, were urged by him in favor of the stimulation hypothesis. These objections, however, were met by Jones, who continued East's experiments with corn. He pointed out that owing to the phenomenon of genetic linkage, which was known to occur in corn as well as in several other plants and animals, the consequences of the dominance hypothesis of hybrid vigor would really be much closer to those of the stimulation hypothesis in the above respects than had been recognized. It should frequently happen that detrimental recessive factors would be linked with favorable dominant ones. In these cases the homozygotes would be of the types AbAb or aBaB, while the heterozygotes would be largely AbaB. The heterozygotes, containing both dominant factors, would be superior to both homozygous types, giving a situation almost indistinguishable from that which follows the stimulation hypothesis. In this suggestion Jones did not add a new hypothesis to the theory of inbreeding; he merely pointed out the logical consequences of a phenomenon, linkage, which had already been demonstrated. The dominance hypothesis was thus greatly strengthened. Collins (1921) has recently shown that even if linkage is disregarded, the objections to the dominance hypothesis are not serious in cases in which

numerous factors are involved. In such cases inbred segregates, homozygous in all factors conducive to vigor would be rare and the degree of skewness would be imperceptible.

It may be added that even if only one or two factors are involved, the skewness in F_2 would be imperceptible if environmental influences play an important part in the variation. In the experiments on guinea pigs described in the present paper, over 90 per cent of the variation in such characters as size of litter and weight is demonstrably due to factors which are not genetic. No significant differences in skewness or even in variation can be found between inbreds and second generation crossbreds. But none is to be expected under such conditions.

Finally, the success which some livestock breeders have had with close inbreeding and which Darwin obtained in at least one case with his morning glories indicates that inbred lines are produced occasionally which are thoroughly satisfactory from the standpoint of vigor. This point has been demonstrated most conclusively in the extensive experiments of the Wistar Institute conducted by Dr. Helen D. King (1918). In this experiment a strain of rats (two lines since the seventh generation) has been inbred, brother with sister, for 22 generations. Not only has full vigor been maintained but the inbreds have actually come to surpass the random-bred stock of the Wistar Institute in size and fertility. This result she attributes to careful selection. The strain of albino rats used was doubtless also rather homogeneous to begin with. The fact remains that long-continued, intensive inbreeding is not incompatible with a high degree of vigor.[5]

It thus turns out that as far as the facts of inbreeding and crossbreeding are concerned the distinction between the hypotheses is largely one of wording. The choice between them depends on which involves the fewest unproved assumptions. So far as the writer knows, it has not been demonstrated in any specific case that a heterozygote may show an increase in vigor while the two homozygotes are indifferent. On the other hand, it has been noted repeatedly that there is a correlation among known Mendelian characters between dominance and vigor, or, looking at it from the other end, between recessiveness and deleterious effect. Collins (1921) prefers the latter form of statement as suggesting better the probable evolutionary significance of the phenomenon.

Most of the mutations known in *Drosophila* are less vigorous than the normal strain (Morgan, Sturtevant, Muller, and Bridges, 1915). They are also mostly recessive, at any rate as regards detrimental

[5] These experiments have also given a remarkable demonstration of the success of inbreeding associated with close selection, as a method of modifying a character so difficult to deal with as sex ratio. Two lines, separated in the seventh generation, were selected respectively for high and low ratio of males to females. An average sex ratio of about 122 became fixed in one line, about 82 in the other.

effects. It is logical that there should be such a relation. The chances are much greater that any mutation will be injurious than beneficial, on the principle that anything done at random to a complex mechanism will probably damage it. Even if dominant and recessive mutations occur with equal frequency, the latter should accumulate more rapidly, since they can be carried along out of the range of natural selection, while injurious dominant mutations will tend to be eliminated at once.

Thus logically we should expect to find that recessive factors would more frequently be deleterious than dominant ones, and study of the known factors shows that such a situation actually exists. Given the Mendelian mechanism of heredity, and this more or less perfect correlation between recessiveness and detrimental effect, and all of the long-known effects of inbreeding—the frequent appearance of abnormalities, the usual deterioration in size, fertility, and constitutional vigor in the early generations, the absence of such decline in any one or all of these respects in particular cases, and the fixation of type and prepotency attained in later generations—are the consequences to be expected.

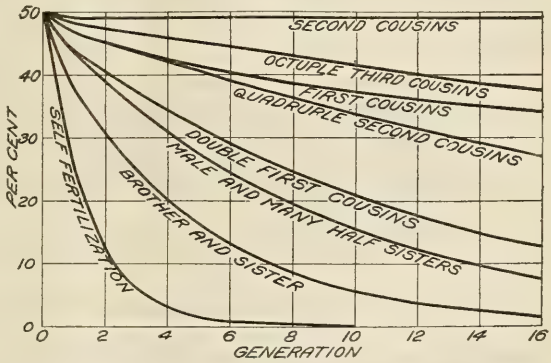

FIG. 24.—The decrease in heterozygosis in successive generations of inbreeding according to various systems of mating.

MATHEMATICAL CONSIDERATION.

The primary effect of inbreeding on this theory is the automatic increase in homozygosis. Jennings (1912) showed that with self-fertilization the percentage of heterozygotes is halved in each successive generation. The decrease following brother-sister mating was worked out by Fish (1914) and Pearl (1914). Various other systems, such as continued mating of parent with offspring, were given by Jennings (1916, 1917). A method of calculating more remote systems has been given by the writer in a previous paper (1921). Figure 24 shows the decline in heterozygosis under various systems, starting from a random-bred stock.

In Figure 24 the random-bred stock is represented as being 50 per cent heterozygous, which implies that dominant and recessive factors are equally numerous. It is easy to show, however, that the rate of decline is the same regardless of the ratio of recessive to total factors. The general formula for a random-bred population is $x^2AA+2xy$

$Aa+y^2aa$ where x and y are the relative proportions of dominant and recessive genes. The proportion of heterozygosis in the random-bred stock is thus $2xy$. Let p be the percentage of heterozygosis after a certain amount of inbreeding. Then $\left(x-\frac{p}{2}\right)AA+pAa+\left(y-\frac{p}{2}\right)aa$ represents the composition of the population. The correlation between uniting gametes (f) comes out $1-\frac{p}{2xy}$, applying the product-moment method to the above formula. Thus $p=2xy(1-f)$. In the calculations (Wright, 1921) on which the percentages in Figure 24 are based, the formula $p=\frac{1}{2}\left(1-f\right)$ was used, which, as stated, applies to the case in which $x=y=\frac{1}{2}$. The formula for f under the various systems of inbreeding applies to any composition of the population. Thus the decline in the percentage of heterozygosis shown in the figure applies to any population provided merely that the scale is changed so that the percentage under random mating is $2xy$ instead of 50 per cent.

As regards the rate of decline in vigor (if any), it is easy to show that it is proportional to the decline in heterozygosis, regardless of the relative number of dominant and recessive genes, and regardless of the degree of dominance. In the population $\left(x-\frac{p}{2}\right)AA+p\,Aa+\left(y-\frac{p}{2}\right)aa$ the mean deviation from the dominant type is $p\,(Aa)+\left(y-\frac{p}{2}\right)(aa)$, where (Aa) represents the deviation of the heterozygotes (zero if dominance is perfect) and (aa) represents that of the recessives. The deviation in the ultimate inbred population, $xAA+yaa$, is $y\,(aa)$. Thus the deviation at any time from the ultimate level is the difference $p\,[\frac{1}{2}(aa)-(Aa)]$. This is proportional to p, the percentage of heterozygosis regardless of the values of x and y, or of the degree of dominance. Thus Figure 24 should represent the rate at which vigor declines, relative to the ultimate level, under any conditions under the various systems of mating. The absolute rate of decline, if any, depends of course on the factors in the particular case.

In comparing the theoretical with the actual rate of decline, it must of course be borne in mind that the character which is being studied must be measured on a scale such that unit differences at all parts of the range are physiologically equivalent. A correction may be necessary such as we have used in the case of percentage born alive and similar cases. In other cases a logarithmic scale may be the proper one to use (Zeleny, 1920).

We have seen that the inbred lines of guinea pigs have actually deteriorated in regard to all characters which have been studied. Unfortunately we can not make a satisfactory comparison of the rate at which this decline has taken place with theory because of the great fluctuations from year to year which are evidently due to environmental causes. We can, however, compare the records of the various crossbreeding experiments with their theoretical relations to the inbred average, since we have calculated all of them on the basis of the inbreds raised simultaneously.

Let x and y represent as before the relative proportions of any pair of factors, A and a, in the original random-bred population. We will start by assuming that the same proportions apply to the group of inbred families which are used for crossing. This implies that there has been no selection and also that enough families are taken to represent adequately the original stock. The composition of the

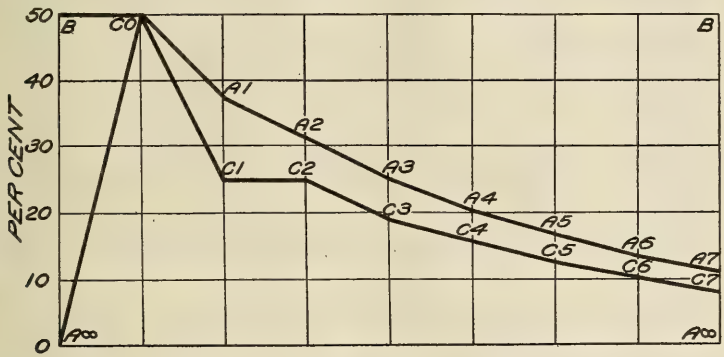

FIG. 25.—The decrease in heterozygosis and correspondingly in vigor in successive generations of inbreeding brother with sister, beginning with a random-bred stock (B, A1, A2, A3, etc.), or beginning with a first cross between homozygous lines (C0, C1, C2, C3, etc.).

first crossbred generation (CO) will then be $x^2AA+2xyAa+y^2aa$. In spite of the apparent identity with the composition of the random-bred stock, inbreeding of CO does not give the same result. This is because there is necessarily a perfect correlation between brothers and sisters in the first cross between lines assumed to have reached homozygosis, while there is a correlation of only $+.50$ in the random-bred stock. The results of three generations of brother-sister mating from the first cross (C1, C2, C3) are worked out in detail in Table 12 and are compared with the effects of such mating in a random-bred stock (or CC, CA, or AC) in Figure 25. There is a more rapid initial decline in vigor on starting inbreeding from the first crossbred generation. The first inbred generation (C1) is composed in part of true breeding lines (AA and aa) and in part of a group which is composed of $\frac{1}{4}AA+\frac{1}{2}Aa+\frac{1}{4}aa$, like a random-bred stock in which $x=y$, but with zero correlation between brothers and sisters. In the next generation

TABLE 12.—*Analysis of the effects of brother-sister mating following crosses between homozygous inbred lines, x of type AA and y of type aa.*

C0.					C1.				C2.				C3.			
Sire.	Dam.	AA.	Aa.	aa.	Parents.	AA.	Aa.	aa.	Parents.	AA.	Aa.	aa.	Parents.	AA.	Aa.	aa.
x *AA*	*A*	x^2			AA x AA	x^2			AA x AA	x^2			AA x AA	x^2		
									AA x AA	$\frac{xy}{8}$			AA x AA	$\frac{xy}{8}$		
													AA x AA	$\frac{xy}{8}$		
									AA x Aa	$\frac{xy}{4}$	$\frac{xy}{4}$		AA x Aa	$\frac{xy}{8}$	$\frac{xy}{8}$	
													Aa x Aa	$\frac{xy}{32}$	$\frac{xy}{16}$	$\frac{xy}{32}$
									AA x aa		$\frac{xy}{4}$		Aa x Aa	$\frac{xy}{16}$	$\frac{xy}{8}$	$\frac{xy}{16}$
x *AA*	y *aa*												AA x AA	$\frac{xy}{32}$		
													AA x Aa	$\frac{xy}{16}$	$\frac{xy}{16}$	
													AA x aa		$\frac{xy}{16}$	
			2xy		Aa x Aa	$\frac{xy}{2}$	xy	$\frac{xy}{2}$	Aa x Aa	$\frac{xy}{8}$	$\frac{xy}{4}$	$\frac{xy}{8}$	Aa x Aa	$\frac{xy}{32}$	$\frac{xy}{16}$	$\frac{xy}{32}$
													Aa x aa		$\frac{xy}{16}$	$\frac{xy}{16}$
y *aa*	x *AA*												aa x aa			$\frac{xy}{32}$
													Aa x Aa	$\frac{xy}{32}$	$\frac{xy}{16}$	$\frac{xy}{32}$
									Aa x aa		$\frac{xy}{4}$	$\frac{xy}{4}$	Aa x aa		$\frac{xy}{8}$	$\frac{xy}{8}$
													aa x aa			$\frac{xy}{8}$
									aa x aa		$\frac{xy}{4}$	$\frac{xy}{4}$	aa x aa			$\frac{xy}{8}$
y *aa*	y *aa*			y^2	aa x aa			y^2	aa x aa			y^2	aa x aa			y^2
Total....	.....	x^2	2xy	y^2	.....	$\frac{xy}{2}+x^2$	xy	$\frac{xy}{2}+y^2$	.....	$\frac{xy}{2}+x^2$	xy	$\frac{xy}{2}+y^2$	.....	$\frac{5xy}{8}+x^2$	$\frac{3}{4}xy$	$\frac{5xy}{8}+y^2$

(C2) the true breeding lines of course remain the same, while the remaining portion gives rise to a population with unchanged total composition, but with a correlation of +.50 between brothers and sisters. There is thus no difference in the percentage of heterozygosis in C1 and C2, both being just halfway between CO and the ancestral inbred families. From this point the percentage declines as if from a random-bred stock halfway between the inbreds and the original random-breds. The percentage of heterozygosis in the later generations is about 75 per cent of its value in the same generation, starting from random-bred stock. Thus about 4 per cent of the original vigor of heterozygosis should be left after 15 generations of brother-sister mating beginning with random-bred stock, but only 3 per cent after 15 generations of such mating, following a first cross between inbred lines.

In our actual experiments only a limited number of families were used in making the crosses. This of course makes no difference in the average of the first cross (C0), provided that the particular inbred lines used are typical. By the use of selected inbred lines, on the other hand, it should be possible to produce a first cross superior to the random-bred stock.

The rate of decline on inbreeding the first cross in case an indefinitely large number of families is involved is of course merely the average of the results in particular cases. Thus the number of families used makes no difference in our conclusions as to experiments C1 and C2.

Whatever the number of families, crosses among the crossbreds in which no family is used twice, as in experiments CA, AC, and CC, are equivalent to random mating among an indefinitely large number of families. Thus the total composition and the percentage of heterozygosis should be the same in CA, AC, and CC as in C0. As already noted, however, the effects of renewed inbreeding are different.

It is only when we come to consider the effects of random mating, resumed after crossing, that we must take account of the number of families which form the foundation of the new stock. Random mating of stock derived from a small number of homozygous lines involves an appreciable amount of inbreeding and thus should give results intermediate between experiments such as C0, CC, CA, and AC, in which inbreeding is avoided, and C1, in which there is brother-sister mating. In the extreme case in which only two families are used, random mating is of course the same as brother-sister mating for one generation. There comes to be only half as much heterozygosis as in the original stock from which the two parental families were derived. The vigor of the new random breds should thus be halfway between that of the original stock and of the inbreds.

It is not difficult to find the percentage of heterozygosis under random breeding from stock derived from any given number of families. Assume that there are n families. Symbolize each family by a letter P, Q, R, S, etc. There are $\frac{n}{2}(n-1)$ different first crosses (PQ, PR, PS, QR, etc.). On commencing random breeding there is one chance in $\frac{n}{2}(n-1)$ of making a mating in which both families are used twice (like PQ×PQ) and which is thus equivalent to a mating of experiment C1. There are $2(n-2)$ chances in $\frac{n}{2}(n-1)$ of making matings in which one family only is used twice, (like PQ×QR). There are $\frac{1}{2}(n-2)(n-3)$ chances in $\frac{n}{2}(n-1)$ of making matings in which neither family is used twice, (like PQ×RS) and which are equivalent to Experiment CC. In the last case, as we have seen, there is complete recovery, on the average, of the heterozygosis of the original random-bred stock. In the first case (PQ×PQ) there is only half-recovery. One might expect to find an exactly intermediate result in the case (PQ×QR), and this can easily be shown to be true by the use of path coefficients (Wright, 1921).

Since P, Q, R, and S are assumed to be completely homozygous inbred families, the constitution of the germ cells is completely determined. Thus the path coefficient from zygote to germ cell (b') is 1.0 in the first generation. As there is assumed to be no correlation between the families and hence none between their germ cells ($f'=0$), the coefficient for the degree of determination of the progeny (first cross) by germ cells (a'^2) equals $\frac{1}{2}$. For the correlation between mated individuals of the next generation we have in consequence $m=1$ in the case PQ×PQ; $m=\frac{1}{2}$ in the case PQ×QR, and $m=0$ in the case PQ×RS. For the path coefficient, zygote to germ cell, second generation, we have $b=\sqrt{\frac{1}{2}}$, by the formula $b^2=\frac{1}{2}(1+f')$. For the correlation between uniting germ cells of this generation we have $f=b^2m$. Finally, by the formula for percentage of heterozygosis, $p=2xy\ (1-f)$, we have $p=xy$ in the case PQ×PQ, $p=3/2\ xy$ in the case PQ×QR, and $p=2xy$ in the case PQ×RS. Thus the second case is exactly intermediate between the others, as we set out to prove.

Multiplying the number of matings of each kind by the corresponding percentage of heterozygosis and adding, we find the total percentage of heterozygosis in the new random-bred stock to be $100\times\frac{xy(n-1)^2}{n/2\ (n-1)}=100\times\frac{2xy(n-1)}{n}$ where $100\times 2xy$ is the percentage in the original random-bred stock. Since each pair of factors comes to equilibrium after one generation of random mating, this level of

heterozygosis will remain true indefinitely. Summing up, a random-bred stock derived from n inbred families will have $\frac{1}{n}$th less superiority over its inbred ancestry than the first cross or a random-bred stock from which the inbred families might have been derived without selection.

COMPARISON OF RESULTS WITH THEORY.

In the foregoing theoretical considerations we have assumed that the characteristics depend on the heredity of the progeny produced by the mating in question. It will be recalled, however, that we found good reason for believing that most of the characteristics in the experiments with guinea pigs were really determined wholly or in part by the parents, in most cases the dam, as far as these characteristics were genetic at all. In a character determined wholly by the dam, Experiments C0 and CA belong with the inbreds, CC, AC, and C1 represent the first cross, and C2 represents the first generation of

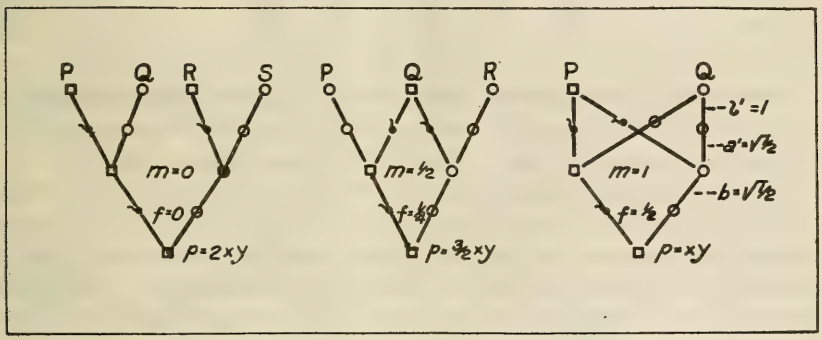

FIG. 26.—The percentage of heterozygosis following matings among inbred families of the types PQ x RS PQ x QR, and PQ x PQ. Original families, x of type AA and y of type aa.

renewed inbreeding. In characters determined partly by the parents and partly by the progeny we can easily find the relations which are to be expected by combining the expectations based on the breeding of the dam and sire with those based on the progeny. Table 13 shows the expectation in certain cases, while Figure 27 presents some of the same conclusions graphically.

TABLE 13.—*The vigor of heterozygosis to be expected in various experiments with respect to characters determined in various degrees by the sire, dam, and the animal in question.*

Character determined by—			Vigor of heterozygosis, 1 in random-bred stock, 0 in ultimate inbred stock.							
Sire.	Dam.	Young.	B.	A1.	A2.	A3.	A4.	A5.	A∞.	C0.
0	0	1	1	0.750	0.625	0.500	0.406	0.328	0	1.000
0	¼	¾	1	.812	.656	.531	.430	.347	0	.750
0	½	½	1	.875	.687	.562	.453	.367	0	.500
0	¾	¼	1	.938	.719	.594	.476	.386	0	.250
0	1	0	1	1.000	.750	.625	.500	.406	0	0
½	½	0	1	1.000	.750	.625	.500	.406	0	0
1	0	0	1	1.000	.750	.625	.500	.406	0	0

Character determined by—			Vigor of heterozygosis, 1 in random-bred stock, 0 in ultimate inbred stock.								
Sire.	Dam.	Young.	C1.	C2.	C3.	C4.	C5.	C∞.	CA.	AC.	CC.
0	0	1	0.500	0.500	0.375	0.312	0.250	0	1.000	1.000	1.000
0	¼	¾	.625	.500	.406	.328	.261	0	.750	1.000	1.000
0	½	½	.750	.500	.438	.344	.281	0	.500	1.000	1.000
0	¾	¼	.875	.500	.469	.354	.296	0	.250	1.000	1.000
0	1	0	1.000	.500	.500	.375	.312	0	0	1.000	1.000
½	½	0	1.000	.500	.500	.375	.312	0	.500	.500	1.000
1	0	0	1.000	.500	.500	.375	.312	0	1.000	0	1.000

Note that Experiments CC with the full vigor of the original stock and C2 with half this vigor are constant in position regardless of the relative importance of sire, dam, or the young themselves.

These theoretical conclusions are based solely on the hypothesis that the hereditary element in the various characters is determined wholly by Mendelian factors and that there is more tendency for the detrimental factors to be recessive than dominant. Comparison with the actual results (Fig. 27) shows that the agreement is as close as could be reasonably expected.

Adult weight and resistance to tuberculosis are examples of characters determined wholly by the young themselves. The percentage raised of the young born alive seems to be determined about three-fourths by the heredity of the young and one-fourth by the dam. In total percentage raised, rate of gain between birth and weaning, and weight at weaning, the breeding of the dam and of the young are about equally important. The data for birth weight indicate that here the breeding of the dam counts for about three-fourths, young only one-fourth or less. The percentage born alive depends almost completely on the dam. In frequency of litter, the heredity of young counts for nothing, but the sire seems to have twice as much influence as the dam. In size of litter there is complete determination by the dam. The young per year and young raised per year are merely combinations of certain of the other characters. For the last named there is something like one-eighth determination by the young.

One result which seemed rather puzzling was the relatively low record of Experiment CG, in which the parents were selected as ex-

ceptionally heavy and vigorous at weaning. In this case, as in CL, matings were made at random as far as ancestry was concerned. In many cases the same family enters into the ancestry of both parents of a given animal in these experiments. For this reason, as we have just seen, a lower record is to be expected than in Experiment CC, in which no family was used twice.

SUMMARY AND GENERAL CONCLUSIONS.

The Bureau of Animal Industry has conducted experiments for 15 years on the effects of inbreeding on guinea pigs. About 34,000 animals have been recorded. These include the records of 23 separate families, each descended from an original pair exclusively by matings of brother with sister (over 25,000 animals), a control stock

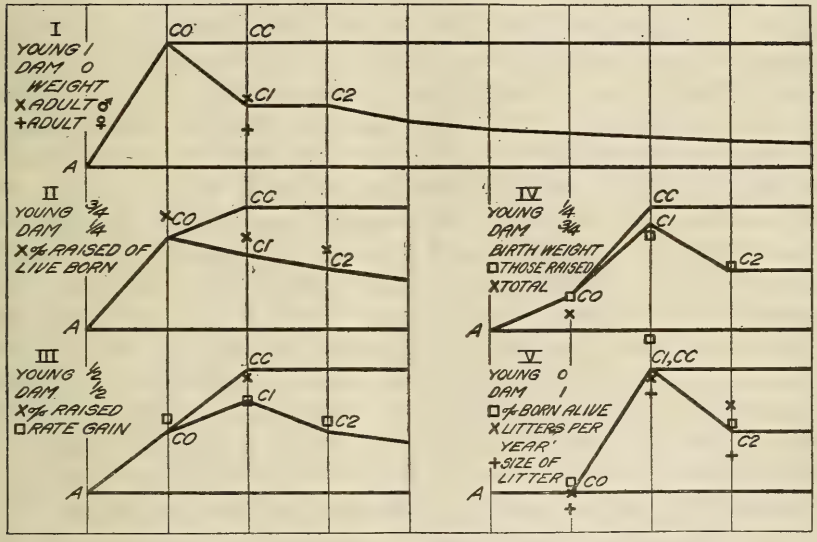

FIG. 27.—The vigor under crossbreeding (C0) and under renewed inbreeding (C1, C2, C3, etc.) relative to that in the inbred stock (A) and under continued crossbreeding (CC). Characters depending in various degrees (I-V) on dam (or sire) and young.

in which inbreeding has been carefully avoided (over 4,000 animals), and crosses among the inbred families (nearly 5,000 animals).

The fact that inbreeding of the closest possible kind has been carried on for over 20 generations in several families, without any very obvious degeneration, is a noteworthy result.

There has been on the average, however, a decline in all elements of vigor. The mortality at birth and between birth and weaning, the weight at various ages, the regularity in producing litters, the size of litter and the resistance to tuberculosis are the principal characteristics which have been studied in this connection.

Fully as important as the fact of an average decline in vigor, is the conspicuous differentiation among the families, which has been brought to light and increased by the inbreeding. This has been

most obvious in the fixation of such characteristics as color, number of toes, and tendency toward the production of particular types of abnormalities. There has also, however, been a significant differentiation in the averages made in all elements of vigor. These elements of vigor have proved to be inherited independently of each other. Each family has come to be characterized by a particular combination of traits, usually involving strength in some respects with weakness in others.

Crosses between different inbred families have resulted in a marked improvement over both parental stocks in every respect, due allowance having been made for the effects of size of litter on the other characters. This improvement appears to its full extent in the progeny of the first cross in the case of adult weight (about 12 per cent) and resistance to tuberculosis (about 20 per cent). The mortality between birth and weaning is found to depend about three-fourths on the breeding of the young and one-fourth on that of the dam. There is thus a marked improvement in the first cross (about 11 per cent) in spite of the inbred dam, but there is some additional advance in the progeny of a crossbred dam with an unrelated male. In the rate of gain between birth and weaning, the breeding of the dam and of the young are about equally important. An improvement of about 16 per cent was obtained in this respect. Birth weight depends largely on the dam—about three-fourths—and only one-fourth on the breeding of the young. There is thus only slight improvement before the second generation in which it amounted to some 9 per cent. The mortality at birth is almost wholly a maternal affair. Crossbreeding of the dam adds about 7 per cent to the chances of the young. The heredity of the young also counts for nothing in frequency or size of litter. The sire is somewhat more responsible than the dam in the former case; the dam seems to be wholly responsible in the latter. Frequency of litter was increased over 30 per cent and size of litter over 10 per cent when both sire and dam were crossbred.

The number of young raised per year by an average mating depends on four of the above elements of vigor—the mortality at birth, that between birth and weaning, and the frequency and size of litters. The relatively small improvement in crossbred matings in each separate respect as given above, is compounded into an advance of over 80 per cent in the combination, which goes well beyond the superiority of the random-bred control stock over the inbreds.

Analysis of the various crosses, indicates that the results are all the direct or indirect consequence of the Mendelian mechanism of heredity. The fundamental effect of inbreeding is the automatic increase in homozygosis in all respects. An average decline in vigor is the consequence of the observed fact that recessive factors, more extensively brought into expression by an increase in homo-

zygosis, are more likely to be deleterious than are their dominant allelomorphs. The differentiation among the families is due to the chance fixation of different combinations of the factors present in the original heterozygous stock. Crossing results in improvement because each family in general supplies some dominant factors lacking in the others. Dominance or even imperfect dominance in each unit character is built up into a pronounced improvement over both parent stocks in the complex characters actually observed.

A certain portion of the increase in vigor of the first cross between inbred families is maintained on resuming random mating. One-half of this increase is maintained in stock founded on 2 inbred lines, two-thirds in the case of 3 lines, three-fourths in the case of 4 lines, four-fifths in the case of 5 lines and so on.

It is believed that the results point the way to an important application of inbreeding in the improvement of livestock. Nearly all of the characteristics dealt with here, like most of those of economic importance with livestock, are of a kind which is determined only to a slight extent by heredity in the individual. About 70 per cent of the individual variation in resistance to tuberculosis and over 90 per cent of that in the rate of gain, and size of litter is determined by external conditions. Progress by ordinary selection of individuals would thus be very slow or nil. A single unfortunate selection of a sire, good as an individual, but inferior in heredity, is likely at any time to undo all past progress. On the other hand, by starting a large number of inbred lines, important hereditary differences in these respects are brought clearly to light and fixed. Crosses among these lines ought to give a full recovery of whatever vigor has been lost by inbreeding, and particular crosses may safely be expected to show a combination of desired characters distinctly superior to the original stock. Thus a crossbred stock can be developed which can be maintained at a higher level than the original stock, a level which could not have been reached by selection alone. Further improvement is to be sought in a repetition of the process—the isolation of new inbred strains from the improved crossbred stock, followed ultimately by crossing and selection of the best crosses for the foundation of the new stock.

This method of improvement has not been unknown in the past. In fact, most of the recognized breeds of livestock were developed, more or less unconsciously, in this way. Close inbreeding was practiced by the pioneer breeders—Bakewell, the Collings, Bates, Cruickshank, Hewer, etc. The relatively few promising families and the successful nicks between them were the foundation stock of the breeds. Further development may be expected by the intelligent application of the same principles.

TABLE 14.—*Data on the fertility in the various inbreeding and crossbreeding experiments, 1916–1919.*

Experiment.	Size of litter.							Number of mating years.	Number of litters.	Number of young.	Average size of litter.	Average litters per year.	Average young per year.	Average young raised per year.
	1	2	3	4	5	6	7							
2	87	187	133	32	2	....	....	119.3	441	998	2.26	3.70	8.37	5.00
13	45	115	85	33	12	3	....	90.7	293	740	2.53	3.23	8.16	4.30
32	60	81	63	18	1	....	....	67.8	223	488	2.19	3.29	7.20	3.91
35	64	120	108	40	9	....	....	94.9	341	833	2.44	3.59	8.78	5.11
39	39	53	51	17	2	1	....	56.3	163	382	2.34	2.90	6.79	3.39
Other	119	210	140	44	7	....	....	194.5	520	1,170	2.25	2.67	6.01	2.80
Inbred	414	766	580	184	33	4	....	623.5	1,981	4,611	2.33	3.18	7.40	3.96
C0	134	235	157	51	11	....	....	183.2	588	1,334	2.27	3.21	7.28	4.48
CA	31	57	46	23	7	....	....	39.4	164	410	2.50	4.16	10.41	7.99
AC	19	41	57	44	15	8	....	48.2	184	571	3.10	3.82	11.85	9.02
CC	42	69	82	35	9	1	....	54.3	238	617	2.59	4.38	11.36	7.61
C1	50	77	73	39	10	....	....	57.4	249	629	2.53	4.34	10.96	7.46
C2	13	31	19	10	2	....	....	17.6	75	182	2.43	4.26	10.34	7.10
CL	21	40	44	22	6	5	....	33.8	138	381	2.76	4.08	11.27	8.31
CG	32	64	56	41	13	4	....	47.4	210	581	2.77	4.43	12.26	8.16
B	81	188	212	78	21	7	1	159.6	588	1,559	2.65	3.68	9.77	6.71

TABLE 15.—*Percentage born alive.*

[Average in litters of each size, the combined average, and the index (litters of 1, 2, 3, and 4 weighted 1, 3, 3, and 1, respectively). Inbreeding and crossbreeding experiments, 1916–1919.]

Experiment.	Size of litter.							Total.	Index.
	1	2	3	4	5	6	7		
2	69.0	78.9	77.4	67.2	30.0	.....	.....	75.5	75.6
13	82.2	81.7	77.6	65.2	48.3	0.0	.....	72.7	78.2
32	86.7	90.1	76.2	61.1	0.0	.....	.....	79.1	80.8
35	70.3	89.6	78.7	63.1	42.2	.....	.....	76.2	79.8
39	87.2	85.8	81.0	60.3	90.0	100.0	.....	79.8	81.0
Other	82.4	80.2	75.5	53.4	31.4	.....	.....	73.2	75.4
Inbred	78.7	83.0	77.4	61.4	43.0	25.0	.....	75.3	77.7
C0	85.1	87.1	75.6	63.2	52.7	.....	.....	77.7	79.5
CA	87.1	86.8	86.2	80.4	71.4	.....	.....	83.9	85.8
AC	73.7	92.7	91.2	90.3	86.7	72.9	.....	88.4	89.5
CC	85.7	86.2	89.4	77.9	71.1	50.0	.....	84.1	86.3
C1	90.0	93.5	84.9	80.8	70.0	.....	.....	85.2	88.2
C2	92.3	90.3	78.9	85.0	90.0	.....	.....	85.7	85.6
CL	95.2	96.2	92.4	69.3	73.3	63.3	.....	84.3	91.3
CG	84.4	89.8	89.3	73.8	60.0	62.5	.....	80.4	86.9
B	84.0	91.0	85.4	81.1	81.0	52.4	0.0	84.2	86.8

TABLE 16.—*Percentage raised to 33 days of the young born alive.*

[Average in litters of each size, the combined average, and the index (see Table 15). Inbreeding and crossbreeding experiments, 1916–1919.]

Experiment.	Size of litter.							Total.	Index.
	1	2	3	4	5	6	7		
2	81.7	83.7	79.9	62.8	0.0	.....	.....	79.3	79.4
13	78.4	76.6	72.2	67.4	55.2	.....	.....	72.5	74.0
32	84.6	74.0	63.9	47.7	.....	.....	.....	68.7	68.2
35	80.0	79.5	78.0	71.3	36.8	.....	.....	76.4	78.0
39	76.5	74.7	61.3	39.0	55.6	0	.....	62.6	65.4
Other	70.4	70.9	53.9	63.8	45.5	.....	.....	63.5	63.6
Inbred	77.6	76.8	68.9	62.2	46.5	0	.....	71.2	72.1
C0	88.6	88.0	83.1	76.7	51.7	.....	.....	84.0	84.8
CA	96.3	92.9	89.9	89.2	96.0	.....	.....	91.6	91.7
AC	92.9	92.1	91.7	86.8	76.9	60.0	.....	86.1	91.4
CC	91.7	86.6	85.0	69.7	37.5	66.7	.....	79.6	84.5
C1	88.9	85.4	79.0	77.8	57.1	.....	.....	79.9	82.5
C2	100.0	87.5	86.7	61.8	44.4	.....	.....	80.1	85.5
CL	75.0	89.6	86.9	90.2	90.9	84.2	.....	87.5	86.8
CG	85.2	88.7	86.7	80.2	66.7	60.0	.....	82.9	86.4
B	83.8	86.3	82.7	79.8	67.1	50.0	.....	81.6	83.8

TABLE 17.—*Percentage raised to 33 days of all young, born dead or alive.*

[Average in litters of each size, the combined average, and the index (see Table 15). Inbreeding and crossbreeding experiments, 1916–1919.]

Experiment.	Size of litter.							Total.	Index.
	1	2	3	4	5	6	7		
2	56.3	66.0	61.9	42.2	0	.....	.....	59.8	60.3
13	64.4	62.6	56.1	43.9	26.7	0	.....	52.7	58.0
32	73.3	66.7	48.7	29.2	0	.....	.....	54.3	56.1
35	56.2	71.3	61.4	45.0	15.6	.....	.....	58.2	62.4
39	66.7	64.2	49.7	23.5	50.0	0	.....	50.0	54.0
Other	58.0	56.9	40.7	34.1	14.3	.....	.....	46.5	48.1
Inbred	61.1	63.8	53.3	38.2	20.0	0	.....	53.6	56.3
C0	75.4	76.6	62.8	48.5	27.3	.....	.....	65.3	67.8
CA	83.9	80.7	77.5	71.7	68.6	.....	.....	76.8	78.8
AC	68.4	85.4	83.6	78.4	66.7	43.7	.....	76.2	81.7
CC	78.6	74.6	76.0	54.3	26.7	33.3	.....	66.9	73.1
C1	80.0	79.9	67.1	62.8	40.0	.....	.....	68.0	73.0
C2	92.3	79.0	68.4	52.5	40.0	.....	.....	68.7	73.4
CL	71.4	86.2	80.3	62.5	66.7	53.3	.....	73.8	79.2
CG	71.9	79.7	77.4	59.1	40.0	37.5	.....	66.6	75.3
B	70.4	78.5	70.6	64.7	54.3	26.2	0	68.7	72.8

TABLE 18.—*Average birth weight in grams of all young, born dead or alive.*

[Average in litters of each size and the index (litters of 1, 2, 3, and 4 weighted 1, 3, 3, and 1, respectively). Inbreeding and crossbreeding experiments, 1916–1919.]

Experiment.	Size of litter.							Index.
	1	2	3	4	5	6	7	
2	86.0	72.0	60.1	50.5	44.5			66.6
13	101.9	80.8	68.4	59.2	50.7	39.5		76.1
32	98.1	80.0	66.4	57.4	52.5			74.3
35	96.5	84.5	70.1	56.6	50.4			77.1
39	85.8	72.6	63.0	50.4	53.5	37.8		67.9
Other	93.0	75.3	64.9	53.5	43.6			70.9
Inbred	93.0	77.0	65.3	54.7	48.9	38.9		71.8
C0	97.7	77.6	64.4	53.9	48.5			72.2
CA	107.0	86.0	72.5	63.3	56.6			80.7
AC	100.3	95.8	75.7	65.9	60.3	48.8		85.1
CC	101.8	86.9	70.2	59.1	51.1	71.2		79.0
C1	104.2	84.4	69.8	63.5	51.7			78.8
C2	104.5	84.8	72.9	61.0	58.5			79.8
CL	104.5	90.8	78.3	66.0	56.5	53.3		84.7
CG	106.7	87.5	79.0	62.8	59.2	54.0		83.6
B	101.2	86.9	71.8	61.7	57.0	54.7	24.5	79.9

TABLE 19.—*Average birth weight, in grams, of young which were raised to weaning.*

[Average in litters of each size and the index (see Table 18). Inbreeding and crossbreeding experiments, 1916–1919.]

Experiment.	Size of litter.							Index.
	1	2	3	4	5	6	7	
2	94.9	76.9	65.8	58.4				72.7
13	110.8	88.7	75.2	67.1	63.9			83.7
32	103.5	84.0	70.9	63.1				78.9
35	104.5	87.3	74.4	63.6	63.1			81.6
39	91.1	76.4	68.3	60.8	60.5			73.3
Other	101.3	80.4	69.4	58.8	56.5			76.1
Inbred	100.9	82.1	70.4	61.9	62.0			77.6
C0	101.9	82.9	71.3	61.9	63.2			78.3
CA	110.5	89.9	74.1	69.0	60.7			83.9
AC	111.4	98.4	77.4	67.9	63.7	55.5		88.3
CC	103.6	89.5	72.3	67.8	55.3	74.5		82.1
C1	107.0	85.6	74.3	67.2	63.5			81.7
C2	105.3	86.7	77.6	65.0	59.5			82.9
CL	110.5	91.3	74.8	74.0	63.0	58.9		85.4
CG	111.9	91.3	82.9	70.0	67.6	66.7		88.1
B	111.5	90.8	75.0	67.7	63.0	60.0		84.6

TABLE 20.—*Average daily rate of gain between birth and weaning (33 days), in grams.*

[Average in litters of each size and the index (see Table 18). Inbreeding and crossbreeding experiments, 1916–1919.]

Experiment.	Size of litter.							Index.
	1	2	3	4	5	6	7	
2	3.58	3.20	2.95	2.78				3.10
13	5.06	4.54	3.99	3.67	3.05			4.29
32	4.32	4.27	3.24	2.96				3.73
35	4.98	4.44	3.92	3.39	2.88			4.18
39	4.31	3.90	3.09	2.80	3.91			3.51
Other	4.50	3.48	2.98	2.52	2.70			3.30
Inbred	4.43	3.85	3.36	3.09	3.09			3.64
C0	5.15	4.31	3.82	3.40	3.10			4.12
CA	5.51	4.93	3.98	3.66	3.02			4.49
AC	5.49	5.06	4.23	3.53	3.45	3.77		4.61
CC	5.34	5.12	3.81	3.77	2.80	5.61		4.49
C1	5.36	4.63	4.07	3.46	3.24			4.37
C2	5.68	4.58	4.73	3.40	4.09			4.62
CL	6.27	5.16	4.69	4.14	2.62	3.92		4.99
CG	5.80	5.20	4.63	3.90	4.04	5.20		4.90
B	5.49	4.77	3.83	3.50	3.27	3.54		4.35

TABLE 21.—*Average weight at weaning (33 days), in grams.*

[Average in litters of each size and the index (see Table 18). Inbreeding and crossbreeding experiments, 1916–1919.]

Experiment.	Size of litter.							Index.
	1	2	3	4	5	6	7	
2	213.2	182.4	163.3	150.2				175.1
13	277.8	238.5	206.8	188.1	164.5			225.2
32	246.1	225.0	177.7	160.9				201.9
35	269.0	233.8	203.6	175.6	158.0			219.6
39	233.3	205.1	170.3	153.2	189.5			189.1
Other	249.8	195.1	167.7	142.1	145.5			185.0
Inbred	247.1	209.0	181.4	163.8	164.0			197.8
C0	271.7	225.1	197.5	174.0	165.5			214.2
CA	292.9	252.7	205.4	189.8	160.3			232.1
AC	292.6	265.5	216.9	184.3	177.5	179.9		240.5
CC	279.8	258.6	198.1	192.1	147.8	259.5		230.3
C1	284.0	238.5	208.5	181.3	170.5			225.8
C2	292.8	237.7	233.6	177.1	194.5			235.5
CL	317.5	261.6	229.6	210.6	149.5	188.3		250.2
CG	303.4	263.0	235.7	198.6	201.0	238.4		249.8
B	292.6	248.3	201.4	183.2	170.9	176.7		228.1

TABLE 22.—*Number of mature matings during successive 3-month periods, 1916–1919. Inbreeding and crossbreeding experiments.*

Experiment.	1916				1917				1918				1919				Year matings total.
	1–3	4–6	7–9	10–12	1–3	4–6	7–9	10–12	1–3	4–6	7–9	10–12	1–3	4–6	7–9	10–12	
2	29.0	32.3	33.0	31.0	29.0	21.7	22.3	21.0	22.7	28.7	31.0	32.7	37.3	39.0	34.0	32.7	119.4
13	36.7	33.7	34.0	31.3	24.3	16.0	16.0	14.0	12.3	13.7	17.0	18.0	19.3	23.7	25.3	27.7	90.7
32	23.3	20.0	19.0	19.0	17.0	13.0	12.0	15.0	17.0	17.0	11.7	12.3	13.7	18.0	19.0	24.0	67.8
35	29.7	24.7	23.0	22.3	20.3	18.7	16.3	20.7	22.3	21.0	20.0	22.3	22.3	29.7	31.0	35.3	94.9
39	32.3	25.3	23.7	21.0	18.7	16.7	12.0	8.7	7.7	7.3	6.3	5.0	7.3	10.0	10.7	12.3	56.3
Other	142.0	123.0	107.3	100.7	101.0	76.3	52.0	31.3	17.0	12.3	7.0	4.7	3.3	.....	.....	.....	194.5
Inbred	293.0	259.0	240.0	225.3	210.3	162.3	130.7	110.7	99.0	100.0	93.0	95.0	103.3	120.3	120.0	132.0	623.4
C0	3.0	39.0	51.3	72.3	82.3	75.3	68.3	53.7	49.0	47.7	38.3	34.7	31.0	24.3	33.7	28.7	183.2
CA	.....	.....	.....	1.3	2.7	4.0	5.0	6.0	6.7	6.0	8.0	10.0	16.7	30.7	32.0	28.7	39.4
AC	.....	.....	.....	.....	0.3	1.0	3.0	10.0	10.0	8.3	11.3	19.0	22.3	31.3	39.3	36.7	48.2
CC	.....	.....	.3	6.0	11.7	22.3	36.7	32.7	33.0	26.7	20.0	19.0	8.7	.....	.....	.....	54.3
C1	.....	.....	.3	7.0	14.0	19.0	26.0	29.0	32.3	28.0	24.0	24.7	13.3	7.3	4.3	.3	57.4
C2	.....	.....	.....	.....	.3	1.3	4.7	6.0	8.7	7.7	10.0	11.7	9.3	6.3	3.3	1.0	17.6
CL	.....	.....	.....	.....	.....	.....	.....	2.7	10.7	12.7	12.7	12.7	16.0	26.0	22.0	19.7	33.8
CG	.....	.....	.....	.....	.....	.....	.....	4.7	18.3	19.0	16.0	19.0	28.3	33.0	29.3	21.7	47.4
B	43.0	44.7	51.3	50.3	48.7	43.3	41.0	35.0	39.0	35.0	34.0	35.3	39.7	35.0	28.3	34.7	159.6

TABLE 23.—*Number of litters born during successive 3-month periods, 1916–1919. Inbreeding and crossbreeding experiments.*

Experiment.	1916				1917				1918				1919				Total.
	1–3	4–6	7–9	10–12	1–3	4–6	7–9	10–12	1–3	4–6	7–9	10–12	1–3	4–6	7–9	10–12	
2	30	26	33	27	23	25	16	22	24	22	27	30	42	36	33	25	441
13	25	26	31	22	16	9	14	15	9	10	10	15	19	23	28	21	293
32	20	16	18	15	12	11	8	16	12	11	11	8	14	18	15	18	223
35	26	20	20	23	17	15	19	18	19	15	22	18	23	26	28	32	341
39	22	19	16	18	10	12	8	9	6	7	4	2	6	6	6	12	163
Other	107	67	83	71	61	48	34	22	14	6	4	3	.....	.....	.....	.....	520
Inbred	230	174	201	176	139	120	99	102	84	71	78	76	104	109	110	108	1,981
C0	.....	17	43	56	67	63	76	44	36	29	25	22	24	24	31	31	588
CA	.....	.....	.....	.....	4	3	6	5	8	6	7	14	16	33	37	25	164
AC	.....	.....	.....	.....	.....	1	3	8	8	10	9	17	22	38	33	35	184
CC	.....	.....	1	7	12	22	47	39	33	28	21	19	9	.....	.....	.....	238
C1	.....	.....	.....	10	13	22	28	35	34	27	27	25	14	9	5	.....	249
C2	.....	.....	.....	.....	.....	2	6	7	12	6	10	11	10	6	4	1	75
CL	.....	.....	.....	.....	.....	.....	.....	1	11	7	11	12	21	31	24	20	138
CG	.....	.....	.....	.....	.....	.....	.....	9	21	20	14	21	33	36	29	27	210
B	43	36	46	45	44	40	42	33	35	30	31	34	39	33	28	29	588

TABLE 24.—*Number of young born during successive 3-month periods, 1916–1919. Inbreeding and crossbreeding experiments.*

Experiments.	1916				1917				1918				1919				Total.
	1–3	4–6	7–9	10–12	1–3	4–6	7–9	10–12	1–3	4–6	7–9	10–12	1–3	4–6	7–9	10–12	
2	59	61	78	62	47	59	36	47	49	46	56	67	100	91	82	58	998
13	59	47	90	50	37	18	34	41	24	23	21	37	58	62	79	60	740
32	44	31	41	35	24	24	17	33	24	26	28	15	26	43	39	38	488
35	69	48	58	64	41	33	43	41	41	39	53	45	54	60	71	73	833
39	50	44	41	44	26	26	13	21	13	16	12	4	16	17	12	27	382
Other	240	154	192	163	124	101	80	49	38	14	8	7	.....	.....	.....	.....	1,170
Inbred	521	385	500	418	299	261	223	232	189	164	178	175	254	273	283	256	4,611
C0	.....	32	100	118	140	137	174	97	80	63	56	57	58	64	77	81	1,334
CA	.....	.....	.....	.....	4	7	13	10	19	11	14	30	38	85	116	63	410
AC	.....	.....	.....	.....	.....	1	5	26	17	31	28	44	68	134	102	115	571
CC	.....	.....	2	16	28	51	128	90	95	68	57	48	34	.....	.....	.....	617
C1	.....	.....	.....	22	30	53	70	89	91	73	64	66	29	29	13	.....	629
C2	.....	.....	.....	.....	.....	5	11	18	30	12	22	26	26	18	12	2	182
CL	.....	.....	.....	.....	.....	.....	.....	2	27	18	25	32	50	90	83	54	381
CG	.....	.....	.....	.....	.....	.....	.....	21	49	46	43	49	105	111	82	75	581
B	115	86	139	115	105	110	106	93	87	71	79	79	123	94	82	75	1,559

TABLE 25.—*Number of young born alive during successive 3-month periods, 1916–1919. Inbreeding and crossbreeding experiments.*

Experiment.	1916				1917				1918				1919				Total.
	1–3	4–6	7–9	10–12	1–3	4–6	7–9	10–12	1–3	4–6	7–9	10–12	1–3	4–6	7–9	10–12	
2	29	49	56	42	25	39	26	43	42	34	44	59	79	71	67	48	753
13	38	35	62	36	29	12	21	28	21	11	18	30	38	56	61	42	538
32	27	20	36	27	15	19	17	25	16	19	22	15	19	41	37	31	386
35	47	36	48	45	32	20	33	35	39	19	43	37	45	44	49	63	635
39	35	32	39	28	18	18	13	19	12	13	7	4	15	16	11	25	305
Other	156	108	134	136	87	74	72	40	22	13	8	7	.....	.....	.....	.....	857
Inbred	332	280	375	314	206	182	182	190	152	109	142	152	196	228	225	209	3,474
C0	.....	22	77	71	92	115	135	86	67	42	34	47	50	54	69	76	1,037
CA	.....	.....	.....	.....	4	7	13	8	11	9	12	21	31	72	99	57	344
AC	.....	.....	.....	.....	.....	1	5	24	13	20	24	42	65	124	92	95	505
CC	.....	.....	2	13	26	41	102	78	77	58	49	46	27	.....	.....	.....	519
C1	.....	.....	.....	17	18	48	62	78	80	66	52	51	29	25	10	.....	536
C2	.....	.....	.....	.....	.....	4	11	12	26	11	18	26	24	15	8	1	156
CL	.....	.....	.....	.....	.....	.....	.....	2	16	13	19	30	43	75	73	50	321
CG	.....	.....	.....	.....	.....	.....	.....	20	32	34	28	48	79	97	73	56	467
B	93	71	121	98	79	96	90	83	65	48	64	76	112	81	70	66	1,313

TABLE 26.—*Number of young raised to weaning (33 days) during successive 3-month periods, 1916–1919. Inbreeding and crossbreeding experiments.*

Experiment.	1916				1917				1918				1919				Total
	1–3	4–6	7–9	10–12	1–3	4–6	7–9	10–12	1–3	4–6	7–9	10–12	1–3	4–6	7–9	10–12	
2	14	36	47	29	15	30	14	38	34	24	31	55	72	56	60	42	597
13	20	24	43	24	17	6	19	17	15	4	11	30	28	50	49	33	390
32	17	13	29	16	3	16	14	16	8	8	11	15	17	34	27	21	265
35	25	27	35	31	19	14	30	32	30	11	28	36	36	36	42	53	485
39	13	25	23	15	6	13	7	16	7	8	3	3	13	12	9	18	191
Other	70	81	102	78	42	60	53	31	9	7	6	5	.....	.....	.....	.....	544
Inbred	159	206	279	193	102	139	137	150	103	62	90	144	166	188	187	167	2,472
C0	.....	16	62	54	63	103	110	79	55	33	31	43	43	50	66	63	871
CA	.....	.....	.....	.....	4	7	11	5	10	6	11	20	27	68	91	55	315
AC	.....	.....	.....	.....	.....	1	5	17	10	9	22	39	60	104	85	83	435
CC	.....	.....	1	8	12	41	74	74	59	44	37	45	18	.....	.....	.....	413
C1	.....	.....	.....	8	12	40	55	70	59	41	39	46	29	20	9	.....	428
C2	.....	.....	.....	.....	.....	2	11	9	13	9	15	26	24	10	5	1	125
CL	.....	.....	.....	.....	.....	.....	.....	2	10	11	16	27	35	69	67	44	281
CG	.....	.....	.....	.....	.....	.....	.....	18	19	28	22	48	61	80	64	47	387
B	74	60	97	75	52	80	75	72	57	38	44	74	85	66	61	61	1,071

TABLE 27.—*Indices and averages, showing the record of the total inbred stock in various characteristics during successive 3-month periods, 1916–1919.*

Character.	1916				1917				1918				1919			
	1–3	4–6	7–9	10–12	1–3	4–6	7–9	10–12	1–3	4–6	7–9	10–12	1–3	4–6	7–9	10–12
Per cent born alive	65.6	74.5	80.4	78.3	67.1	69.9	84.1	83.8	82.1	69.9	80.7	87.3	81.9	84.0	86.0	84.0
Per cent raised of born alive	47.3	74.6	78.8	61.8	47.6	73.0	76.5	79.3	68.6	57.0	66.0	94.7	86.2	87.3	87.6	80.0
Per cent raised	32.4	56.0	63.0	49.3	32.8	53.8	63.9	66.8	57.0	40.4	53.0	82.7	70.5	73.4	75.8	67.9
Birth weight (total)	69.6	71.0	68.5	71.9	64.5	65.0	66.3	75.3	69.8	63.8	66.0	81.9	83.1	83.1	79.1	76.6
Birth weight (raised)	76.3	77.9	73.6	77.6	72.3	72.4	70.9	78.0	73.3	71.1	73.0	85.1	85.2	85.7	81.9	78.3
Gain	3.18	3.32	3.04	3.15	3.19	3.07	3.70	4.11	3.55	2.72	3.22	5.20	4.43	4.43	3.89	3.73
Weight, 33 days	181.3	187.4	174.0	181.4	177.6	173.8	192.9	213.6	190.6	160.8	179.1	256.8	231.5	232.0	210.3	201.3
Size of litter	2.27	2.21	2.49	2.38	2.15	2.18	2.25	2.27	2.25	2.31	2.28	2.30	2.44	2.50	2.57	2.37
Litters per year	3.14	2.69	3.35	3.13	2.64	2.96	3.03	3.68	3.39	2.84	3.36	3.19	4.03	3.62	3.67	3.27
Young per year	7.12	5.94	8.33	7.42	5.68	6.43	6.82	8.38	7.62	6.56	7.67	7.35	9.84	9.07	9.43	7.76
Young raised per year	2.17	3.18	4.65	3.43	1.94	3.43	4.19	5.42	4.16	2.48	3.87	6.06	6.43	6.25	6.23	5.06
Sex ratio	120.3	88.3	93.2	104.0	105.0	111.0	109.9	90.0	86.3	118.1	116.5	98.8	130.6	110.2	102.2	101.6

TABLE 28.—*Indices and averages showing the estimated record of the total inbred stock during the period in which each experiment was in progress.*

Experiment.	Per cent born alive.	Per cent raised of those born alive.	Per cent raised.	Birth weight, total.	Birth weight of those raised.	Gain per day.	Weight at 33 days.	Size of litter.	Litters per year.	Young per year.	Young raised per year.
				Grams.	*Grams.*	*Grams.*	*Grams.*				
2	79.3	76.4	60.6	73.5	78.8	3.81	204.6	2.34	3.27	7.69	4.42
13	79.5	75.4	60.7	73.6	78.9	3.79	203.9	2.35	3.23	7.57	4.21
32	78.6	74.2	58.4	72.6	78.3	3.72	201.0	2.34	3.24	7.59	4.24
35	79.1	73.9	59.2	72.9	78.0	3.74	201.4	2.34	3.27	7.68	4.40
39	76.6	70.8	54.4	71.2	77.3	3.54	194.2	2.32	3.17	7.34	3.85
Other	74.3	65.4	49.7	69.0	75.0	3.28	183.2	2.29	3.03	6.93	3.30
Inbred	77.7	72.1	56.3	71.8	77.6	3.64	197.8	2.33	3.18	7.40	3.96
C0	79.0	74.1	58.8	71.0	76.4	3.64	196.6	2.31	3.18	7.35	4.09
CA	83.6	83.0	70.1	77.9	81.0	4.02	213.8	2.41	3.48	8.42	5.42
AC	83.3	83.2	69.4	78.2	81.7	4.12	217.7	2.41	3.49	8.45	5.51
CC	79.9	72.6	58.9	70.0	75.2	3.71	197.6	2.27	3.22	7.31	4.17
C1	79.8	73.5	59.6	71.2	76.3	3.77	200.8	2.29	3.25	7.46	4.31
C2	82.3	78.9	65.3	74.8	79.3	4.10	214.5	2.33	3.40	7.96	4.94
CL	83.4	83.3	69.5	78.2	81.7	4.10	217.0	2.42	3.47	8.38	5.32
CG	82.6	81.9	67.5	77.4	81.3	4.10	216.6	2.40	3.48	8.39	5.32
B	78.4	73.3	58.2	72.1	77.3	3.66	198.0	2.32	3.22	7.51	4.19

TABLE 29.—*Indices and averages showing the record of each experiment during the portion of the 4 years, 1916–1919, in which it was in progress.*

Experiment.	Per cent born alive.	Per cent raised of those born alive.	Per cent raised.	Birth weight, total.	Birth weight of those raised.	Gain per day.	Weight at 33 days.	Size of Litter.	Litters per year.	Young per year.	Young raised per year.
				Grams.	*Grams.*	*Grams.*	*Grams.*				
2	75.6	79.4	60.3	66.6	72.7	3.10	175.1	2.26	3.70	8.37	5.00
13	78.2	74.0	58.0	76.1	83.7	4.29	225.2	2.53	3.23	8.16	4.30
32	80.8	68.2	56.1	74.3	78.9	3.73	201.9	2.19	3.29	7.20	3.91
35	79.8	78.0	62.4	77.1	81.6	4.18	219.6	2.44	3.59	8.78	5.11
39	81.0	65.4	54.0	67.9	73.3	3.50	189.1	2.34	2.90	6.79	3.39
Other	75.4	63.6	48.1	70.9	76.2	3.30	185.0	2.25	2.67	6.01	2.80
Inbred	77.7	72.1	56.3	71.8	77.6	3.64	197.8	2.33	3.18	7.40	3.96
C0	79.5	84.8	67.8	72.2	78.3	4.12	214.2	2.27	3.21	7.28	4.48
CA	85.8	91.7	78.8	80.7	83.9	4.49	232.1	2.50	4.16	10.41	7.99
AC	89.5	91.4	81.7	85.1	88.3	4.61	240.5	3.10	3.82	11.85	9.02
CC	86.3	84.5	73.1	79.0	82.1	4.49	230.3	2.59	4.38	11.36	7.61
C1	88.2	82.5	73.0	78.8	81.7	4.37	225.8	2.53	4.34	10.96	7.46
C2	85.6	85.5	73.4	79.8	82.9	4.62	235.5	2.43	4.26	10.34	7.10
CL	91.3	86.8	79.2	84.7	85.4	4.99	250.2	2.76	4.08	11.27	8.31
CG	86.9	86.4	75.3	83.6	88.1	4.90	249.8	2.77	4.43	12.26	8.16
B	86.8	83.8	72.8	79.9	84.6	4.35	228.1	2.65	3.68	9.77	6.71

TABLE 30.—*Differences between the records of each experiment and those of the total inbred stock, raised simultaneously.*

[Obtained by subtracting the entries in Table 28 from those in Table 29. 1916–1919.]

Experiment.	Per cent born alive.	Per cent raised of those born alive.	Per cent raised.	Birth weight, total.	Birth weight of those raised.	Gain per day.	Weight at 33 days.	Size of litter.	Litters per year.	Young per year.	Young raised per year.
				Grams.	*Grams.*	*Grams.*	*Grams.*				
2	−3.7	+3.0	−0.3	−6.9	−6.1	−0.71	−29.5	−0.08	+0.43	+0.68	+0.58
13	−1.3	−1.4	−2.7	+2.5	+4.8	+.50	+21.3	+.18	.00	+.59	+.09
32	+2.2	−6.0	−2.3	+1.7	+0.6	+.01	+0.9	−.15	+.05	−.39	−.33
35	+0.7	+4.1	+3.2	+4.2	+3.6	+.44	+18.2	+.10	+.32	+1.10	+.71
39	+4.4	−5.4	−1.4	−3.3	−4.0	−.04	−5.1	+.02	−.27	−.55	−.46
Other	+1.1	−1.8	−1.6	+1.9	+1.2	+.02	+1.8	−.04	−.36	−.92	−.50
C0	+1.5	+10.7	+9.0	+1.2	+1.9	+.48	+17.6	−.04	+.03	−.07	+.39
CA	+2.2	+8.7	+8.7	+2.8	+2.9	+.47	+18.3	+.09	+.68	+1.99	+2.57
AC	+6.2	+8.2	+12.3	+6.9	+6.6	+.49	+22.8	+.69	+.33	+3.40	+3.51
CC	+6.4	+11.9	+14.2	+9.0	+6.9	+.78	+32.7	+.32	+1.16	+4.05	+3.44
C1	+8.4	+9.0	+13.4	+7.6	+5.4	+.60	+25.0	+.24	+1.09	+3.50	+3.15
C2	+3.3	+6.6	+8.1	+5.0	+3.6	+.52	+21.0	+.10	+.86	+2.38	+2.16
CL	+7.9	+3.5	+9.7	+6.5	+3.7	+.89	+33.2	+.34	+.61	+2.89	+2.99
CG	+4.3	+4.5	+7.8	+6.2	+6.8	+.80	+33.2	+.37	+.95	+3.87	+2.84
B	+8.4	+10.5	+14.6	+7.8	+7.3	+.69	+30.1	+.33	+.46	+2.26	+2.52

TABLE 31.—*Estimated probable errors of the indices and averages of Table 29.*

Experiment.	Per cent born alive.	Per cent raised of those born alive.	Per cent raised.	Birth weight, total.	Birth weight of those raised.	Gain per day.	Weight at 33 days.	Size of litter.	Litters per year.	Young per year.	Young raised per year.
				Grams.	*Grams.*	*Grams.*	*Grams.*				
2	1.2	1.2	1.3	0.40	0.47	0.044	1.71	0.028	0.060	0.190	0.154
13	1.3	1.6	1.6	.48	.59	.056	2.16	.042	.085	.216	.174
32	1.5	2.0	1.9	.57	.70	.066	2.56	.042	.096	.239	.199
35	1.2	1.4	1.4	.44	.53	.050	1.91	.037	.071	.217	.173
39	1.7	2.3	2.2	.65	.84	.079	3.06	.055	.123	.258	.217
Other	1.1	1.4	1.3	.37	.49	.047	1.80	.028	.072	.134	.115
Inbred	.5	.6	.6	.19	.23	.022	.85	.015	.033	.080	.066
C0	1.0	.9	1.1	.35	.39	.037	1.43	.027	.060	.146	.123
CA	1.5	1.3	1.8	.64	.67	.064	2.45	.057	.079	.359	.284
AC	1.2	1.2	1.5	.59	.60	.057	2.19	.063	.088	.343	.261
CC	1.2	1.4	1.6	.52	.58	.054	2.09	.047	.058	317	.240
C1	1.1	1.4	1.6	.52	.57	.054	2.07	.047	.058	.303	.232
C2	2.2	2.4	2.8	.95	1.04	.099	3.80	.078	.111	.537	.418
CL	1.2	1.7	1.8	.66	.73	.069	2.67	.070	.091	.401	.308
CG	1.3	1.4	1.6	.56	.61	.058	2.23	.056	.059	.351	.259
B	.8	.9	1.0	.33	.36	.034	1.32	.030	.052	.174	.137

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ABSORPTION BY COLLOIDAL AND NONCOLLOIDAL SOIL CONSTITUENTS.

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INTRODUCTION.

Absorption[1] by soils has been investigated since the early days of soil science. Nevertheless, the parts played by the different soil constituents in absorption phenomena have not been accurately determined. It has been recognized in a general way that the finer soil particles are more absorptive than the larger particles and that organic constituents are among the most highly absorptive. However, very few accurate quantitative data have been obtained on the absorptive capacities of soil particles of different sizes.

A soil is of course a very intimate mixture of many components, and it would seem at first thought unreasonable to allocate such a general property as absorption to any one class of constituents. However, in 1909, Ashley (*2*)[2] proposed the absorption of malachite green as a measure of the relative colloidal contents of ceramic clays. This was equivalent to assuming that practically all the absorption of the clay was due to colloids and that the colloids in different clays

[1] The term "absorption" is used in this paper in the general sense, for which "sorption" has recently been proposed. It is not intended to convey any idea of the mechanism of the process as is done by the term "adsorption" or by "absorption" used in a more specific sense.

[2] Reference is made by number (italic) to "Literature Cited," p. 19.

had similar absorptive capacities. In 1912 Mitscherlich (*16*, p. 476) made a general statement that the hygroscopicity of noncolloidal soil particles was almost nothing, but that the colloids in different soils must have different capacities for absorbing water vapor. Evidence recently accumulated in this laboratory also seems to show that practically all the absorptive capacity of the soil is located in the colloidal material. For instance, samples of the colloidal matter, or "ultra clays,"[3] extracted from a large number of different soils by use of a high-power centrifuge,[4] show absorptive capacities for malachite green, ammonia gas, and water vapor which are two to twenty times higher than those of the original soils.

Moore, Fry, and Middleton, (*17*) of this bureau, have suggested that the colloidal content of the soil may be measured by comparing the absorptive power of the soil for malachite green or ammonia gas with the absorptive power of the mixed colloids, or ultra clay, extracted from the soil, if soil absorption is due almost entirely to the colloids. While the various ultra clays absorb widely different amounts of malachite green and of ammonia gas, they have a much more constant absorptive capacity for water vapor. It was, therefore, suggested by Robinson (*21*) that the colloidal content of the soil might be estimated by dividing its water-absorption value by a factor which is an average of the specific absorptions of a large number of different ultra clays, if the noncolloidal particles do not absorb appreciably. This latter method would obviate the necessity of extracting a sample of colloid from the soil.

Although there is considerable evidence that by far the greater part of the soil's absorptive capacity is due to colloids, it is obviously important to obtain quantitative data on the relative absorptions of the colloidal and noncolloidal constituents, if absorptive methods are to be used for determining the amount of colloids in soils. This paper deals chiefly with the absorptive capacities of the noncolloidal soil particles for malachite green, water, and ammonia. The absorption of such particles is compared with the average absorptive capacities of the ultra clays extracted from different soils. Various colloidal mineral powders and synthetic gels were also tested for absorption in order to throw light on the nature of the soil colloids.

PREVIOUS WORK.

Several investigators, including König and Hasenbäumer (*14*), Ogg and Hendrick (*18*), and Atterberg (*4*) have fractionated soils into various sized particles and determined the absorptive power of the different fractions for substances, such as water, dyes, gases, or salts. The results on the whole show that the absorption by the different sized particles increases with the fineness, although not in a regular manner, and that the finer soil fractions above colloidal size absorb appreciably but much less than the colloidal material. These determinations of the noncolloidal absorption can not be accepted without question, however, since the various soil fractions were probably not entirely free from colloidal material.

[3] The term "ultra clay" has been suggested to denote the mixture of colloidal constituents present in the soil.

[4] Details of the process are given in the paper by Moore, Fry, and Middleton (*17*).

Hundeshagen (*12*) and Dittler (*7*) tested, in a qualitative manner only, the absorption of various minerals for different dyes.

Ammon (*1*), and later Von Dobeneck (*8*), determined the absorptive powers of a number of finely powdered substances, including quartz, calcite, and humus for water vapor, ammonia, and other gases, and found that quartz and calcite showed a small but appreciable absorption while humus absorbed to a marked degree. Using quartz of different degrees of fineness these investigators found absorption higher in the finer fractions, but the increase due to fineness was less than the proportional increase in surface.

Stremme and Aarnio (*24*) showed that rock powders absorb but a small amount of dye and water as compared with the amount absorbed by natural clays or artificial gels. The exact fineness of the rock powders was not given, so the data throw but little light on our problem.

DISTINCTION BETWEEN COLLOID AND NONCOLLOID.

Usually colloids and noncolloids are distinguished by the size of the particles. But this distinction is not all-sufficient, especially when dealing with soil constituents, since an important part of the colloidal material in soils may be present in such a condition that it is not readily dispersable.

In the work reported here, mineral particles larger than 1 micron in diameter are assumed as noncolloids and all particles smaller than this as colloids. All the organic matter of the soil is also classed as colloid, irrespective of whether or not it happens to exist in a state of subdivision less than 1 micron. The insoluble part of more or less decomposed plant remains is of course largely made up of substances such as the celluloses, proteins, and their derivatives, which are universally classified as colloids, although in the dried state those substances may not be readily dispersable.

Certain particles, or more accurately aggregates of particles, larger than 1 micron in diameter, are also classed as colloids. These particles under the ultra microscope show no evidence of being crystalline and appear to be merely aggregates of particles which are less than 1 micron in diameter. They are presumably either difficultly reversible or irreversible colloids.

The use of 1 micron as the dividing line between colloidal and noncollodal mineral particles permits good microscopical control; since the form of particles 1 micron in size can usually be readily distinguished and such particles need not be confused with points of light emanating from very much smaller particles.

Although 1 micron is an arbitrary limit for the upper diameter of colloidal mineral particles, there is some justification for its selection, aside from mere convenience of microscopical observation. Mineral particles which are 1 micron in diameter show a distinct Brownian movement, while larger particles show practically no such activity. The international commission in 1913 decided on 2 microns as the upper limit for colloidal clay (*23*, p. 189).

OUTLINE OF INVESTIGATION.

The most obvious way of obtaining data on the relative absorptions of the colloidal and noncolloidal soil material would be to separate

the soil into two fractions, colloid and noncolloid, and then determine the absorptions of these fractions. This is similar to the method used by earlier investigators and is the one the authors first tried. The work is described under "Estimation of noncolloidal absorption from soil fractions." The data obtained in this way were not considered trustworthy, as it was exceedingly difficult to separate the bulk of the colloidal matter from the larger soil grains and it was practically impossible to tell whether or not a complete separation had been attained.

It was thought that a more accurate estimation of the noncolloidal absorption of the soil could be obtained by investigating the absorption of the individual soil minerals, since the noncolloidal part of the soil is made up of mineral particles of various degrees of fineness above the arbitrary limit of 1 micron. Each of the common soil minerals was ground to the proper fineness and the absorption of the mineral powder was determined. From the absorptive capacities of the different minerals and from the mineralogical composition of the soil, the noncolloidal absorption was calculated. Determinations by this procedure are given under "Estimation of noncolloidal absorption from mineral particles."

An indication of the nature of the colloidal material in soils was also obtained by comparing the absorptive capacities of finely ground minerals and various gels with the absorptive capacities of the mixed colloids which had actually been extracted from soils. This part of the work is detailed under "Evidence concerning the nature of the soil colloids, afforded by absorption data."

METHODS FOR DETERMINING ABSORPTION.

Determinations were made of the absorptive capacities of all samples for malachite green, water vapor, and ammonia gas. The methods followed in determining the absorption of water vapor and ammonia gas have been given in detail in previous publications and therefore need only brief descriptions.

In the absorption of ammonia (*17*) a sample of material which has previously been dried for 18 hours at 110° C. is exposed at 0° C. to dry ammonia gas under atmospheric pressure until absorption is virtually complete. The amount of ammonia driven off by evacuating the material at 100° C. is then determined.

The absorption of water (*21*) involves a determination of the amount of water which the sample will take up when exposed for five days to the vapor of 2 per cent sulphuric acid maintained at a temperature of 30° C.

The method for the absorption of malachite green, which differs somewhat from that described in a previous publication (*17*), is as follows: From 0.25 gram to 1 gram of material is mixed with 25 cubic centimeters of water and shaken over night. After shaking, the suspensions are treated with enough N/10 sodium oxalate solution to precipitate any soluble calcium present. The amount of sodium oxalate which it is necessary to use can be determined by a preliminary test. After adding the sodium oxalate solution, the whole is shaken 15 minutes to insure complete precipitation of the calcium oxalate. Malachite green (a 0.2 per cent solution) is then added with repeated shakings until the depth of color of the super-

natant liquid is practically the same as that of a check solution containing 10 cubic centimeters of the aforementioned dye solution in a total volume of 50 cubic centimeters. This is to insure the absorbed dye being in equilibrium with practically the same concentration of nonabsorbed dye in each determination. The suspensions are then shaken one hour in an end-over-end shaker to insure complete absorption of the dye by the soil. This time is probably longer than necessary in most cases. Sufficient normal sodium chloride solution to coagulate the colloid is then added to the suspensions; usually 5 cubic centimeters is sufficient. After a few minutes settling the suspensions are centrifuged in order to throw out any solid material and the supernatant liquid is read colorimetrically against the check solution.

ESTIMATION OF NONCOLLOIDAL ABSORPTION FROM SOIL FRACTIONS.

METHODS OF SEPARATING SOIL COLLOIDS.

In separating the colloidal matter from the larger soil grains two difficulties are encountered that are inherent in all systems of mechanical analysis: First, the difficulty of obtaining a complete deflocculation of the ultimate soil particles; second, the difficulty of sorting out the particles of different size after they have been deflocculated.

In the system of mechanical analysis heretofore practiced in the Bureau of Soils (*10*), treatment with a few drops of ammonia followed by long shaking have been relied on to bring about deflocculation. Williams (*26*) adopted long continued boiling supplemented by rubbing as the most efficient method of deflocculation. Atterberg (*3*) in deflocculating the soil for his system of mechanical analysis, utilizes rubbing and treatment with an alkaline solution of bromine, with hydrochloric acid and sodium hydroxide, or with concentrated nitric acid, according to the nature of the soil. König and Hasenbäumer (*14*) suggested boiling for a short time and repeated rubbing.

While all these methods probably deflocculate and form good suspensions of part of the colloidal matter, it is not certain that any of them deflocculates all of it. Some colloidal matter adhering to mineral particles may be difficult of separation, and we have evidence in our work that the colloidal matter which is present in the dry soil as more or less indurated aggregates is especially resistant to dispersion. In our attempts at separation we found the use of ammonia and rubbing with a rubber pestle to be especially effective. For instance, two soils when rubbed with distilled water yielded only 5 per cent and 29 per cent of colloid; but when the residues were rubbed with distilled water containing a trace of ammonia further yields of colloid, 3.5 per cent and 13.5 per cent, respectively, were obtained. Other results show the effect of rubbing. A soil that had been agitated 15 times with water containing ammonia failed to give further colloidal suspensions. However, after the pasty residue had been gently rubbed, succeeding treatments with ammonia water yielded additional amounts of colloid.

Separation of the finer particles from the coarser, after deflocculation has been produced, is brought about by subsidence in most methods of mechanical analysis. A much quicker separation, however, can be made by use of a centrifuge. In this particular investigation we made use of both subsidence and centrifuging.

PREPARATION OF SOIL FRACTIONS.

Our aim was to secure only two fractions of the soil, colloid and noncolloid; but we found the separation was facilitated in some cases by dividing the noncolloidal fraction into two groups—a coarser fraction containing the gravel and sands and a finer fraction consisting of particles ranging approximately from 0.001 to 0.050 millimeter in diameter.[5] The colloidal fraction, as previously noted, was made up of particles less than 0.001 millimeter in diameter.

Fractions were obtained from four soils. Details of the procedure were as follows:

Samples of 50 to 100 grams of soil were used, depending on the probable amount of colloidal matter present. The samples were first agitated with distilled water containing ammonia (about 1 part of ammonium hydroxide to 3,000 parts H_2O). The suspension was allowed to settle for several hours and the supernatant liquid containing the finer soil particles was then decanted and whirled for 45 minutes in a bottle centrifuge having a diameter of 22 inches and a speed of 850 revolutions per minute. The material remaining in suspension was poured into the jar containing the colloid fraction. The residues from the centrifuge were combined with the residues left after decantation and were rubbed gently with a rubber pestle, having just enough water present to make a paste. About a liter of water was then added and the subsidence and centrifuging repeated. After 40 to 60 such treatments the residues yielded only the merest trace of colloid and it was evident that no more colloid was to be extracted by these methods. The colloidal matter was concentrated to a thin paste by drawing off the water through Pasteur-Chamberland filters, using suction. The paste of colloidal matter, as well as the coarse residues, was then air-dried.

ABSORPTION BY THE FRACTIONS.

The amounts of the different fractions separated in this manner from four soils of the humid region, together with the absorption per gram of these fractions for malachite green, water vapor, and ammonia gas are shown in Table 1. The quantities of the different fractions obtained are expressed as percentages of the whole soil

TABLE 1.—*Absorptive capacities of different soil fractions.*

Description of soil fractions.	Part of whole soil.	Absorption per gram of material.		
		Malachite green.	Water.	Ammonia.
Huntington loam, soil:	*Per ct.*	*Gram.*	*Gram.*	*Gram.*
Colloid	10.3	0.0949	0.2221	0.0270
Fine fraction	21.9	.0288	.0476	.0098
Coarse fraction	64.0	.0114	.0215	.0062
Huntington loam, subsoil:				
Colloid	13.3	.0918	.2996	.0226
Fine fraction	19.4	.0143	.0665	.0072
Coarse fraction	63.3	.0053	.0292	.0031
Sassafras silt loam, subsoil:				
Colloid	14.4	.1398	.2732	.0293
Fine fraction	20.6	.0222	.0546	.0079
Coarse fraction	61.9	.0053	.0041	.0004
Sharkey clay, soil:				
Colloid	42.4	.3720	.3072	.0516
Fine fraction[a]	53.1	.0657	.0772	.0172

[a] Very little material above 0.050 millimeter present.

[5] This group corresponds approximately to the combined silt and clay groups of the Bureau of Soils classification, except that in this classification no lower limit is given for the clay (*10*).

It will be noted that the soil fractions containing particles from 0.001 to 0.050 millimeter in diameter had absorptive capacities averaging about 25 per cent as great as the corresponding colloids. The coarser soil fractions, made up of particles ranging mostly from about 0.050 to 2 millimeters, had absorptive values which were for the most part much lower than those of the finer fractions.

The absorptions per gram of the noncolloidal soil fractions are thus low as compared with those of the colloids. Nevertheless, if we take into account the relative amounts of the different fractions present in the soil it would appear that from 20 to 70 per cent of the total absorptive capacities of the four soils was due to the noncolloidal particles in these soils. If these data could be taken as accurately representing the absorption values of the noncolloidal part of the soil, it would be evident that the colloidal content of the soil could not be estimated with even approximate accuracy from the absorption of the whole soil.

Although the above data on the absorptive capacities of the noncolloidal soil particles are probably as good as can be obtained by this method of investigation, it is believed that they are not reliable and that they must be considerably higher than the true values. It should be borne in mind that a relatively small contamination with a highly absorptive material, such as the colloidal matter, would appreciably enhance the absorptive capacity of the noncolloidal fractions. Furthermore, we have no positive proof that the noncolloidal fractions were free from colloids. We merely know that all colloid possible was extracted with the means we employed. It is very possible that by some further treatment still more colloid could have been brought into suspension and separated, just as traces of ammonia or gentle rubbing yielded more colloid when mere agitation with distilled water was ineffective.[6]

In the process of separating the colloidal and noncolloidal portions of the soil the size of the particles in the two products was carefully checked by microscopical observation. It was evident from this control that the noncolloidal fraction was practically free from particles smaller than 1 micron in diameter and the colloidal matter contained but very few particles larger than 1 micron. However, if our methods of deflocculation were not perfect, aggregates of colloidal matter, similar to clumps of dried ferric hydroxide, or aluminum silicate gels, or partially decomposed organic matter might well have gone into the noncolloidal fraction. Examination of the dry noncolloidal fractions with the petrographic microscope indicated that this actually occurred. The fractions from the different soils which were made up of particles of 0.001 to 0.050 millimeter in diameter contained from 60 to 75 per cent of particles which could readily be identified as crystalline minerals; the rest of the material was without crystalline properties and had the same general appearance as dried inorganic gels or as the dried soil colloids, which we have separated from the soil with a supercentrifuge.

ESTIMATION OF NONCOLLOIDAL ABSORPTION FROM MINERAL PARTICLES.

Since a complete separation of colloidal from noncolloidal soil material is apparently impossible, owing to the difficulty of dis-

[6] Williams (*26*) relied largely on boiling to bring about dispersion. However, boiling a fine fraction of Huntington subsoil for 18 hours failed to bring about a state of dispersion whereby all the colloid could be removed.

persing some of the colloidal material, reliable data on the noncolloidal absorption in a soil can not well be obtained from an investigation of soil fractions. It was necessary, therefore, to attack the problem in another manner.

If the noncolloidal part of the soil is made up of various mineral particles above the arbitrary limit of 1 micron in diameter, a determination of the absorptive capacities of soil minerals in the proper state of subdivision should afford data for calculating the absorption of the noncolloidal soil constituents. Data obtained in this way should be more reliable than that yielded by the preceding method of investigation, as mineral powders can be prepared which are essentially free from colloidal material.

Some 21 minerals are of common occurrence in soils. Although only a few of these are present in a soil in any considerable quantity, it was thought advisable to determine the absorptive capacity of each of them. Samples of the 21 minerals were kindly provided by the National Museum. They were characteristic mineral specimens, and were apparently free from decomposition products, although not absolutely pure, a few containing traces of calcite.

The work of previous investigators indicates that the absorptive capacity of any one mineral powder is somewhat proportional to the size of the particles,[7] and that some minerals have very low absorptive capacities. It was, therefore, advisable to test samples in a fine state of subdivision in order to obtain an accurate comparison of the absorptive capacities of different minerals. The absorptive capacities of larger particles could then be calculated closely enough for our purpose from the values of the fine particles, on the assumption that the absorptive capacity of any one kind of mineral powder is to a large degree inversely proportional to the size of the particles. Accordingly, a sample of each mineral was prepared which contained only particles ranging in size from 1 to 50 microns in diameter. This group of particles is just above the size we arbitrarily set for the colloids and corresponds to the "fine fraction" separated from the soils in the study just described.

PREPARATION OF MINERAL POWDERS.

After the minerals had been crushed to small pieces in an arbor press and in a steel mortar, they were ground either in an agate mortar or in a steel ball mill, depending on the hardness of the mineral. The harder minerals were more effectively handled in the ball mill. The samples were frequently passed through a 130-mesh sieve in order to obtain the desired fineness with a minimum amount of material finer than 1 micron. The sieved powders were then further graded by subsidence in absolute alcohol in order to remove particles that were larger than 50 microns and smaller than 1 micron in diameter. Absolute alcohol was used for the subsidence rather than water, in order to prevent the formation of colloidal matter by hydrolysis of the mineral.

The mineral powders were carefully examined under the microscope and counts made of the approximate number of particles present in the three following groups: 0.025 to 0.050 millimeter, 0.002 to 0.025 millimeter, and under 0.002 millimeter. There were but

[7] The data of Ammon (*1*) and of Von Dobeneck (*8*) show that while the absorption of any one mineral increases with the degree of subdivision, the increase in absorption is somewhat less than the increase in surface exposed.

very few particles larger than 0.050 millimeter or smaller than 0.001 millimeter in any of the samples. However, the different samples varied considerably in the distribution of the particles between these limits. The approximate surface exposed by 1 gram of each of the mineral powders was calculated. In this estimation account was taken of the specific gravity of the mineral; the mean diameter of each group of particles was taken as the diameter of all particles within the group, and all the particles were assumed to be spheres. No great accuracy can be claimed for these estimates of surfaces, since microscopical counts of particles of the different sizes are probably only accurate to about 10 per cent and certain of the minerals were far from spherical in shape. In the case of muscovite and biotite, the figures for surface represent only a minimum value, since the particles doubtless approximated thin plates rather than spheres. The true surfaces of these powders were probably, therefore, several times the values given in Table 2.

ABSORPTION BY THE DIFFERENT SOIL MINERALS.

In Table 2 are given the amounts of malachite green, water, and ammonia absorbed by 1 gram of each of the mineral powders and the approximate surface exposed in each case.

TABLE 2.—*Absorption of mineral particles 1 to 50 microns in diameter.*

Mineral.	Approximate surface per gram of powdered mineral.	Absorption per gram of mineral.		
		Dye.	H_2O.	NH_3.
	Square centimeter.	*Gram.*	*Gram.*	*Gram.*
[1] Apatite, $CaFCa_4(PO_4)_3$	2,813	.....	0.0015	0.0000
Biotite, $K_2O.4(Mg,Fe)0.2(Al,Fe)_2O_3.6SiO.H_2O$	[2] 1,764	0.0370	.0223	.0012
[1] Calcite, $CaCO_3$	1,225	.....	.0012	.0000
[3] Garnet: $Ca_3Al_2(SiO_4)_3$ / $Fe_3Al_2(SiO_4)_3$	1,687	.0078	.0093	.0008
Chlorite, $H_8(Mg,Fe)_5Al_2Si_3O_{18}$	2,241	.0192	.0148	.0012
Cyanite, Al_2SiO_5	2,619	.0060	.0067	.0006
[3] Epidote: $Ca_2(AlOH)Al_2(SiO_4)_3$ x / $Ca_2(FeOH)Fe_2(SiO_4)_3$ y	1,131	.0001	.0016	.0008
Hornblende: $Ca(Mg,Fe)_2(SiO_3)_3$ / $Na_2Al_2(SiO_3)_4$ / $(Mg,Fe_4)(AlFe_2)SiO_6$	1,165	.0089	.0018	.0000
Limonite, $Fe_2(OH)_6Fe_2O_3$	753	.0053	.0308	.0052
[4] Magnetite, Fe_3O_4	674	.....	.0006	.0000
Microcline, $KAlSi_3O_8$	3,104	.0001	.0008	.0000
Muscovite, $K_2O.3Al_2O_3.6SiO_2.2H_2O$	[2] 2,025	.0390	.0509	.0023
Orthoclase, $KAlSi_3O_8$	3,449	.0005	.0016	.0000
Plagioclase: $NaAlSi_3O_8$ x / $CaAl_2Si_2O_8$ y	3,229	.0000	.0028	.0000
Quartz, SiO_2	3,179	.0000	.0005	.0002
Rutile, TiO_2	694	.0000	.0240	.0012
Sillmanite, Al_2SiO_5	1,609	.0105	.0022	.0008
[3] Titanite, $CaO.TiO_2.SiO_2$	2,694	.0059	.0039	.0010
Tourmaline, $Na_2O,(Fe,Mg,Cr)O,Al_2O_3,SiO_2,B_2O_3,H_2O$	1,386	.0130	.0007	.0000
Zircon, $ZrSiO_4$	977	.0048	.0055	.0012
[3] Zoisite: $Ca_2(AlOH)Al_2(SiO_4)_3$ x / $Ca_2(FeOH)Fe_2(SiO_4)_3$ y	1,166	.0000	.0078	.0007
Average values	1,885	.0088	.0095	.0008

[1] Calcite, and probably apatite, in the absence of colloidal soil material develops an alkaline reaction in the process of the dye determination, and thus decolorizes the malachite green oxalate. This decolorization, however, does not take place when soil material is present to act as a buffer.
[2] Owing to plate-like form of particles, this represents minimum surface.
[3] Trace of calcite present which was removed by 4 per cent HCl before making the dye determination.
[4] Trace of calcite present.

Ammonia gas was not absorbed at all by eight minerals and appreciable amounts were absorbed by only two, muscovite and limonite. Malachite green was absorbed in considerable amounts by muscovite, biotite, and chlorite, and to a lesser degree by tourmaline and several others. Four of the commonest soil minerals, on the other hand, did not absorb a measurable amount of the dye. Water vapor was absorbed by all minerals, although significant amounts were absorbed by only five. The minerals which are usually present in soils in the greatest amount—quartz and the feldspars—showed practically no absorption for the dye, water, or ammonia.

There appeared to be no correspondence between the amounts of malachite green, water, or ammonia absorbed by the different minerals. Rutile, for instance, was highly absorptive of water but not of malachite green or ammonia. On the other hand, tourmaline had a considerable absorption for malachite green, only a very slight absorption for water, and no absorption for ammonia. Limonite, which shows especially high absorption for water and ammonia, is usually considered as being a colloidal mineral. These results agree with Greenland's (*11*) conclusion that crystalline minerals as well as the gel minerals may show some absorption.

While there is of course some proportionality between the outer surface exposed by any one mineral and its absorptive capacity, that is the finer any particular mineral is the more it will absorb, it is apparent from the above table that the absorptive capacities of the different minerals were not proportional to the outer surfaces exposed. Each mineral seems to have a characteristic absorptive capacity for the different substances.

ABSORPTION BY THE MINERAL PARTICLES IN THE SOIL.

With determinations available of the absorptive values of practically all the important unaltered minerals found in normal soils, it is possible to make an approximate evaluation of the part such minerals have in the total absorption of a soil, provided the mineral composition is known.[8] Thus, it is possible to calculate what is probably the truly noncolloidal absorption of the fractions described under "Estimation of noncolloidal absorption from soil fractions." With this in view, a quantitative mineralogical examination was made of the "fine fraction" in each of the soils. The results were as follows:

Huntington loam, soil, fine fraction, 50 per cent quartz, 2 per cent other crystalline minerals, and 48 per cent indeterminate colloid-like material.

Huntington loam, subsoil, fine fraction, 75 per cent quartz, trace of other crystalline minerals, 25 per cent indeterminate colloid-like material.

Sassafras silt loam, subsoil, fine fraction, 60 per cent quartz, 1 per cent muscovite, 1 per cent other minerals, 38 per cent indeterminate colloid-like material.

Sharkey clay loam, soil, fine fraction, 50 per cent quartz, 5 per cent muscovite, 3 per cent other crystalline minerals, 42 per cent indeterminate colloid-like material.

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[8] While optical methods are not applicable for the identification of minerals below 0.005 millimeter in diameter, crystalline outline can usually be distinguished in material down to about 0.001 millimeter.

Table 3 shows, for the four soils studied, that part of the total absorption of the soil which must have been due to the unaltered minerals present. In compiling this table the absorption of each fine fraction was calculated from the mineralogical composition given above and from the absorption data for particles of this size given in Table 2. The absorption of each coarse fraction was calculated from that of the corresponding fine one, assuming that the two fractions were of the same mineralogical composition and that the absorptive values were therefore inversely proportional to the size of the particles.

TABLE 3.—*Part of soil absorption due to unaltered minerals.*

Type of soil.	Absorption of the unaltered minerals present in 1 gram of soil.			Absorption of 1 gram of soil.[1]			Part of soil absorption due to unaltered minerals, in case of—		
	Malachite green.	H_2O.	NH_3.	Malachite green.	H_2O.	NH_3.	Malachite green.	H_2O.	NH_3.
	Gram.	*Gram.*	*Gram.*	*Gram.*	*Gram.*	*Gram.*	*Per cent.*	*Per cent.*	*Per cent.*
Huntington loam, soil	0.0002	0.0002	Trace.	0.0234	0.0508	0.0089	0.8	0.4	Trace.
Huntington loam, subsoil	Trace.	Trace.	Trace.	.0193	.0712	.0064	Trace.	Trace.	Trace.
Sassafras silt loam, subsoil	.0005	.0006	Trace.	.0286	.0530	.0060	1.7	1.1	Trace.
Sharkey clay, soil	.0007	.0009	Trace.	.1880	.1712	.0312	.4	.5	Trace.

[1] Calculated from the absorption given for fractions in Table 1.

It is evident from Table 3 that the absorption of the noncolloidal minerals is less than 2 per cent of the total soil absorption in each of the four soils described and is therefore negligible as compared with the absorption of the colloid. This value for the noncolloidal absorption is very much lower than that shown by the first method of investigation and is, we believe, much more accurate.

The preceding calculations show the relative absorptions of the colloids and noncolloids in four soils only, but a rough estimate can be made for soils in general. The average absorptions per gram of the unaltered common soil minerals of silt and clay size for malachite green, water, and ammonia, as shown in Table 2, are, respectively, 0.0088, 0.0095, and 0.0008, while the averages for ultra clays extracted from some 40 different soils are respectively 0.200, 0.298, and 0.040.[9] The average absorptions per gram of unaltered minerals just above the colloidal size are thus only 4 per cent, 3 per cent, and 2 per cent as high as those of the colloids for malachite green, water, and ammonia.

Since there are such wide variations in the absorptions of the different minerals, a proper estimate can not be made of the relative absorptions of the colloidal and noncolloidal parts of the soil unless consideration is given to the relative quantities in which the different minerals are present. In a former bulletin of the Bureau of Soils (*19*) mineralogical analyses are given of the finer sand and silt groups in 26 representative American soils. The average mineralogical composition of the silt group in these 26 soils is as follows: Quartz 51 per

[9] The extreme variations in the absorptions per gram of the different ultra clays are: 0.431 and 0.070 gram of malachite green, 0.348 and 0.240 gram of water, and 0.076 and 0.019 gram of ammonia.

cent, potash feldspars 7 per cent, muscovite 7 per cent. Miscellaneous minerals, no one of which is present in important amount, together with colloidal aggregates, make up the remaining 35 per cent of the group.[10] The quartz and feldspar mineral powders reported in Table 2 had no appreciable absorption for malachite green, water, or ammonia. It is therefore evident that on an average at least 68 per cent of the mineral particles which are from 1 to 50 microns in size would have practically no absorption. (This is assuming that the minerals in the clay group are essentially the same as those in the silt group.) If we take the average absorption of the other mineral powders as representing the absorption of the remaining 32 per cent of silt and clay particles, the average absorptions per gram of the unaltered minerals in the soil just above the colloidal size would be only 1.7 per cent, 1.1 per cent, and 0.8 per cent that of the average absorption of the ultra clays for malachite green, water, and ammonia, respectively.

In the mechanical groups larger than silt, somewhat over 68 per cent of the mineral particles would probably be quartz and feldspars, since quartz is more abundant in the larger soil separates. Hence in calculating the absorption of mineral particles in the fractions larger than silt, it will be safer to assume that so far as their mineralogical composition is concerned their absorption will be less than that of particles of silt size.

Particles of different sizes of any one crystalline mineral must have absorptive capacities that are to some degree inversely proportional to the size of the particles. On this basis the absorptive capacities of particles from 2 to .25 millimeters in diameter, included in the gravel, coarse sand, and medium sand groups, would be only about one-fortieth as great as that of particles of silt and clay size, and may, therefore, be disregarded. On the same basis, the finer mineral sands, with diameters from 0.05 to 0.25 millimeters would have absorptive capacities one-sixth that of particles of the silt and clay size.

The application of the above facts to a few hypothetical soils will make evident what part the noncolloidal soil particles may be expected to play in the absorption of different types of soils.

Let us assume a loam soil of about average mineral content made up of 45 per cent quartz, 5 per cent muscovite, 5 per cent feldspars, 15 per cent other crystalline minerals, and 30 per cent of colloid. The maximum amount of particles under 0.05 millimeter for a loam soil, according to the classification used in the Bureau of Soils, is 60 per cent. We should then have 60 per cent of material smaller than 0.05 millimeter and 40 per cent larger than 0.05 millimeter. The average size of the latter may well be taken at 0.5 millimeter. If we assume average absorptions for the colloidal matter and calculate the mineral values from Table 2, we should have a gram of the soil absorbing 0.0618 gram dye, 0.0914 gram water, and 0.0121 gram ammonia. The percentages of these total absorptions which were due to the minerals would be respectively 2.9 per cent, 2.2 per cent and 1 per cent. Most of the mineral absorption in this case would be due to mica.

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[10] Recent work has shown that 15 per cent or more of the silt group may consist of colloidal aggregates when this group is separated by the method of mechanical analysis practiced in the Bureau of Soils. Assuming 15 per cent of colloidal aggregates in this group, the average composition of the crystalline minerals would be: Quartz 60 per cent, potash feldspars 8 per cent, muscovite 8 per cent, and miscellaneous minerals 24 per cent.

Although the mineral content assumed in this case is about the average of a large number of soils, most soils do not contain this amount of muscovite. The mica average of 5 per cent is due to the very high mica content of a few important soil types. Usually the muscovite content is below 2 per cent. If the hypothetical soil just considered had contained 2 per cent of muscovite, only approximately 1 per cent of the total absorption would have been due to the crystalline minerals. If, however, the muscovite content had been as high as 37 per cent, which has been reported for one of our most highly micaceous soils, the mineral absorption values might have been as high as 7 to 20 per cent of the total soil absorption, the dye absorption being most affected by the mica.

In the case of a peat soil, the total mineral matter is small in amount, so the absorption of the minerals would be negligible. The organic matter, as indicated before, may be considered essentially colloidal.

EVIDENCE CONCERNING THE NATURE OF SOIL COLLOIDS AFFORDED BY ABSORPTION DATA.

It is difficult to understand why so small a part of the absorptive capacity of the whole soil should reside in the noncolloidal constituents unless the colloidal constituents differ from the noncolloidal in other respects than mere degree of subdivision. The organic matter of soils, which is classified as colloidal, is obviously of a different nature from the mineral particles; but in many soils organic matter forms only a small part of the total colloidal content. Other investigations in this bureau indicate that the larger part of the inorganic colloidal matter in soils is different from the noncolloidal mineral particles in being similar to gels. This view that the soil colloids are mostly of a gel-like nature is also held by Van Bemmelen (*5*), Rohland (22), König (*13*), Ehrenberg (*9*), Wiegner (*25*), and others.

The fact that the mineral powders just above the colloidal size had such low absorptions as compared with the ultra clays is in harmony with the view that the two classes of material are of a different nature. However, since most of the colloidal particles are so small that their size can not be accurately determined microscopically, the possibilities would still remain, so far as microscopical observation is concerned, that the colloidal and noncolloidal parts of the soil are of the same nature and that the differences in absorptian are merely a function of the size of the particles, the colloidal particles being exceedingly fine as compared with the noncolloidal particles.

It therefore became desirable to determine the absorptions of mineral powders ground as finely as possible and to compare the absorptions of these powders with those of the coarser powders and ultra clays.

ABSORPTIVE CAPACITIES OF MINERAL PARTICLES BELOW 1 MICRON IN DIAMETER.

Six minerals which showed but little tendency to flocculate when suspended in water were selected for grinding to colloidal dimensions. The minerals were ground dry in a steel ball mill—muscovite for 10 days and the other minerals for about 3 days. The powders from the ball mill were then shaken with distilled water and the greater part

of the colloidal particles separated from the particles above 1 micron in diameter by means of the centrifuge. This procedure was the same as that followed in separating colloids from soils, except that no ammonia was used with the mineral powders.

Determinations of the absorptive capacities of each of the powdered minerals for malachite green, water, and ammonia are given in Table 4.

TABLE 4.—*Absorption of mineral particles less than 1 micron in diameter.*

Mineral powder.	Absorption per gram of mineral powder.		
	Malachite green.	H_2O.	NH_3.
	Gram.	*Gram.*	*Gram.*
Muscovite	0.0829	0.3581	0.0141
Limonite	.0078	.2289	.0100
Chlorite	.1168	.....	.0091
Microcline	.0000	.1694	.0067
Orthoclase	.0242	.1673	.0077
Quartz	.0000	.0870	.0049
Average	.0386	.2021	.0088

The absorptive powers of these very fine mineral powders for malachite green present striking contrasts. Microcline and quartz did not absorb a detectable amount of dye. On the other hand, chlorite and muscovite had absorptive capacities which were as high as the least absorptive ultra clays found in 33 different soils. In no case was the absorption as high as the average for soil colloids.

The different minerals varied less in their absorptive capacities for water vapor. The values for muscovite and limonite are not greatly different from the average for soil colloids; the others, however, are somewhat lower.

None of the mineral colloids absorbed as much ammonia as the least absorptive ultra clay we have tested, and the average value for the mineral powders is only 22 per cent of the average value for the ultra clays.

While the absorptive capacities of these mineral powders were, on the whole, much greater than those of the 1 to 50 micron powders, they were much lower than those of the ultra clays, particularly as regards absorption of the dye.

The absorptive values obtained for these minerals doubtless did not represent accurately the true absorptive capacities of *unaltered* minerals of any particular size. In preparing these fine powders it was necessary to treat the material with 2 to 10 liters of distilled water for each gram of colloidal mineral extracted, in order to remove completely the coarser particles, and the material was in contact with water for three to five days. There was, therefore, opportunity for considerable alteration or breaking down of the minerals through hydrolysis. Hence, a considerable part of the absorptive capacities of these preparations may well have been due to the presence of colloidal decomposition products of the minerals.

It is well recognized that many silicate minerals are acted upon by distilled water, yielding an alkaline solution and doubtless insolu-

ble hydrolytic products of colloidal nature. This action of course becomes more pronounced the finer the particles. Cushman (*6*) shows that this action takes place to an appreciable extent in a few hours and suggests that a colloidal film is thereby formed on the surface of the particles. Michaelis (*15*) states that some finely powdered quartz which he prepared absorbed water and swelled; also that a silicic acid gel may be made by boiling a quartz suspension for several days. We found that treating powdered orthoclase with hot water for two days, then leaching free from soluble salts, increased its absorptive capacity for water vapor from 0.0016 gram to 0.0046 gram.

The fact that the most finely powdered minerals, even though they must have suffered considerable alteration, had absorptive capacities less than the ultra clays, affords some evidence that the colloidal matter in soils is not made up of merely finely divided minerals. More conclusive evidence of this, however, is afforded by analytical data which are being prepared for publication. These data show that no probable combination of soil minerals has the same chemical composition as the typical colloidal matter in soils.

ABSORPTIVE CAPACITIES OF SYNTHETIC GELS.

It was thought that further evidence on the nature of the colloidal matter in soils might be obtained from the absorptive capacities of inorganic gels; since, as previously stated, other investigations in this bureau indicate that the colloidal material in soils is largely of a gel-like nature. An examination of the ultra clays extracted from many different soils has indicated that they consist chiefly of aluminum silicate with some ferric silicate and one or more of the following substances in the gel form; ferric hydroxide, aluminum hydroxide, organic matter, and possibly silicic acid (*20*). If this is true, it would seem that synthetic preparations of these individual gels should have absorptive capacities of the same order as the ultra clays. Four of these gels were therefore prepared and their absorptions tested.

An aluminum silicate gel was made from sodium silicate and aluminum chloride mixed in the proper proportions for forming kaolinite ($Al_2O_3 . 2SiO_2 . 2H_2O$); the ferric hydroxide was prepared from ferric chloride and sodium hydroxide; the aluminum hydroxide from aluminum chloride and sodium hydroxide; and the silicic acid from sodium silicate and sulphuric acid. The gels thus formed were repeatedly washed with large amounts of distilled water until practically free from soluble salts. The wash waters were removed through Pasteur-Chamberland filters, using suction, and the gels, after being concentrated by air-drying, were ground to pass a 200-mesh sieve.

For comparison with these freshly prepared gels, a sample of silica gel was procured from a commercial chemical company and samples of alumina and iron gels from the Chemical Warfare Service. The absorptive capacities of these products all ground to pass a 200-mesh sieve are shown in Table 5. Included in this table also are the absorptions of a peat soil and of an extract from it containing no particles above 1 micron. The peat soil contained very little mineral matter, so these samples are probably fairly representative of the organic colloids in soils.

TABLE 5.—*Absorption of gels.*

Description of sample.	Absorption per gram of gel.		
	Malachite green.	H_2O.	NH_3.
	Gram.	*Gram.*	*Gram.*
Silica gel:			
Freshly prepared	0.0348	0.8658	0.1426
Commercial product	.0080	.2015	.0966
Aluminum hydrate gel:			
Freshly prepared	.0689	.6155	.0525
Chemical Warfare Service product	.0735	.3500	.0596
Ferric hydrate gel:			
Freshly prepared	.0920	.3090	.0293
Chemical Warfare Service product	.1160	.3106	.0478
Aluminum silicate gel, freshly prepared	.5334	1.0888	.0504
Peat	.2736	.2907	.1274
Peat, particles below 1 micron	.0982	.2990	.0563
Average values	.1443	.4812	.0736

The different gels, just as the mineral powders, varied widely in their absorptive capacities for malachite green, water, and ammonia. It is significant that on the whole the absorptions of the gels were much greater than those of minerals ground below 1 micron, and were in a class with those of the ultra clays. The average absorption of all the gels was somewhat below that of the ultra-clay average for malachite green, but higher for water and ammonia.

A close agreement between the average absorptions of the gels and ultra clays is, of course, not to be expected, since the ultra clays would not be composed of equal amounts of each of these gels. Moreover, the absorptive capacities of synthetic gels vary greatly, according to what appear slight differences in methods of preparation, and they are also profoundly affected by changes generally described as aging. Differences between the absorptive capacities of our gels and those of the chemical company and the Chemical Warfare Service are doubtless due to differences in both method of preparation and age of product.

The absorptive data on colloidal mineral powders and synthetic gels are, on the whole, in harmony with the view that the larger part of the colloidal material in soils is not made up of mineral particles but of substances in a gel-like condition. In itself the absorptive data is not conclusive evidence, but it is confirmatory of similar conclusions arrived at in other investigations.

GENERAL DISCUSSION.

The data accumulated in this work indicate that, as a rule, considerably less than 5 per cent of the absorptive capacity of a soil is located in the unaltered mineral particles and that 95 per cent or more of the absorption is due to the colloidal material. It is realized that this distribution of the absorptive capacity of a soil, which was determined for malachite green, water, and ammonia gas, might not hold for all substances, although these three substances differ widely in their chemical and physical properties.

If 95 per cent or more of the absorption of the whole soil is due to the colloidal constituents, the accuracy of absorptive methods for

determining the colloidal content of a soil obviously would not be affected appreciably by the noncolloidal constituents. One of the fundamental objections against absorptive methods of estimating the colloids is thus removed. It is not intended to imply, however, that even relative colloidal contents of different soils are indicated by the mere absorptive capacities of the soils for such substances as malachite green or ammonia; since the colloids from different soils absorb widely varying amounts of these substances.

The almost complete localization of absorption in the colloidal matter probably is due primarily to the colloidal material being of a quite different nature from the larger soil particles. While the noncolloidal part of the soil is made up of unaltered soil minerals, the colloidal material is doubtless made up chiefly of inorganic gels, the insoluble decomposition product of soil minerals, together with amorphous organic matter.

The results on the noncolloidal absorption of soils are evidently at variance with some of the older, but still prevalent, concepts regarding soil absorption. It has been generally recognized that the organic matter constitutes an especially absorptive part of the soil, and the old view was that the rest of the absorption was due to mineral particles of all degrees of fineness, the finer the particles the more absorptive the soil. Absorption was thus regarded as proportional to the surface exposed, and the surface, except for the organic matter, was considered as being almost entirely that of mineral particles. The more highly absorptive soils were supposed to contain some especially absorptive minerals called zeolites. It is now well recognized that zeolites, if present at all in soils, can be there only in very small amounts.

It is now coming to be realized that the highly absorptive inorganic material in soils is not the definite crystalline zeolites, but amorphous material such as ferric hydroxide, aluminum hydroxide, silicic acid, and aluminum silicate gels. The data here presented tend to confirm the more modern view of soil absorption, and gives for the first time a quantitative estimate of the amount of absorption due to the colloidal material and the amount due to the noncolloidal particles.

SUMMARY.

It was impossible to determine directly the amount of absorption in soils due to colloids and noncolloids from a fractionation of the soil into these two classes of material, since we could not separate all the colloidal matter from the finer mineral particles.

Since the noncolloidal part of soils is made up of minerals of different degrees of fineness, it should be possible to calculate the magnitude of the noncolloidal absorption in the soil from the absorptive capacities of minerals powdered to definite sizes.

Each mineral has a characteristic absorptive capacity for different substances. Several of the most abundant minerals in soils, such as quartz and the feldspars, absorb practically no malachite green, water or ammonia.

It was calculated from the absorption of mineral powders and the mineralogical compositions of soils that as a rule less than 5 per cent of the total absorption of the soil is due to the noncolloidal part. In the case of the most highly micaceous soils, however, the

noncolloidal absorption might reach 10 to 20 per cent of the whole soil absorption.

Absorption by noncolloidal constituents should, therefore, not seriously affect absorptive methods for determining the amount of colloids in soils.

Evidence concerning the nature of the soil colloids is afforded by the absorptive capacities of various substances. Minerals ground to a state of subdivision probably equal to that of the mixed soil colloids, or "ultra clays," absorbed less than the average ultra clay. The average absorption of peat and synthetic inorganic gels, on the other hand, was more nearly like that of the ultra clays.

Since soil colloids appear to be of quite a different nature from the noncolloidal particles, and not merely finely comminuted minerals, it is understandable why such a large part of the absorption of a soil should be localized in the colloidal matter.

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PROPORTIONING THE INGREDIENTS FOR ICE CREAM AND OTHER FROZEN PRODUCTS BY THE BALANCE METHOD.[1]

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THE BALANCE METHOD.

One of the most satisfactory methods that can be used for proportioning the ingredients in making large ice-cream mixes is "the balance method," a term originated in connection with the work here reported. It is a method that can be easily understood, is applicable to all combinations of ingredients, and reduces to a minimum the chances of error in the calculations. Furthermore, it furnishes an itemized record of the ingredients used for each mix. In the examples given, the calculations include decimal fractions, but for all practical trade purposes the nearest whole number is sufficiently accurate, especially when they represent constituents amounting to 100 pounds or more. The proportions obtained by this method are based on five conditions:

1. The amount (pounds) of mix that will be necessary to produce the number of gallons of ice cream desired.
2. The composition (standard) of ice cream desired.
3. The amount of solid constituents necessary for the mix.
4. The quantity and physical condition of the ingredients on hand.
5. The composition of the ingredients to be used.

[1] This bulletin is a technical discussion of a method of calculating mixes of ice cream and other frozen products. It should not be construed as recommending the formulas presented, for not all of them would be legal in all States. Each user should give consideration to the legal standards concerned.

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FIVE BASIC CONDITIONS.

Condition 1.—To get the total number of pounds in the mix, multiply the desired number of gallons of ice cream by the number of pounds expected in one gallon of the finished product. For instance, in the first example 5 pounds is the desired weight of one gallon of ice cream, hence:

$$350 \times 5 = 1{,}750 \text{ pounds of mix.}$$

Condition 2.—The approximate composition of the ice cream desired in the first example is 14.5 per cent fat, 14 per cent sugar, and 6.5 per cent milk solids not fat.

Condition 3.—To find the amount of solid constituents necessary, multiply the pounds of mix by the percentage of fat, sugar, and milk solids not fat as in the first example:

$$1{,}750 \times 0.145 = 253.75 \text{ pounds of fat.}$$
$$1{,}750 \times 0.14 = 245.0 \text{ pounds of sugar.}$$
$$1{,}750 \times 0.065 = 113.75 \text{ pounds of milk solids not fat.}$$

Conditions 4 and 5.—The quantity on hand and composition of the ingredients are as follows:

Ingredients.	Quantity on hand.	Composition.		
		Fat.	Sugar.	Milk solids not fat.
		Per cent.	*Per cent.*	*Per cent.*
Cream	150 pounds	28		6.4
Cream	Plenty	43		5.3
Skim milk	do			9
Condensed milk	430 pounds	10	42	22

After these basic conditions are determined, write the pounds of mix, the percentage of constituents desired, and the pounds of each constituent in table form and list the ingredients to be considered for the mix as shown in Table 1.

HOW THE INGREDIENTS ARE PROPORTIONED.

Five examples of this method of proportioning the ingredients are explained as follows:

EXAMPLE 1.

Give the proportions for 350 gallons of ice cream testing approximately 14.5 per cent fat, 14 per cent sugar, and 6.5 per cent milk solids not fat. The weight of the ice cream desired is 5 pounds per gallon.

Stock on hand: Sugar; 150 pounds of 28 per cent cream; 520 pounds of 43 per cent cream; and skim milk.

TABLE 1.—*Illustration of Example 1.*

Total pounds desired (5×350=1,750).	Ingredients and composition.	Constituents furnished.		
		Fats (14.5 per cent, 253.75 pounds).	Sugar (14 per cent, 245 pounds).	Milk solids not fat (6.5 per cent, 113.7 pounds).
Pounds.		*Pounds.*	*Pounds.*	*Pounds.*
245.0	Sugar		245	
150.0	Cream, 28 per cent	42.00		[1] 10.0
492.5	Cream, 43 per cent	211.77		[1] 26.1
862.5	Skim milk, 9 per cent			77.6
1,750.0		253.77	245	[2] 113.7

[1] The amount of milk solids not fat in the cream is determined by multiplying the difference between the amount of cream used and the amount of fat it contains by 0.093 (the amount of milk solids not fat in the milk serum).

[2] The amount of milk solids not fat in the mix is normal, i. e., the amount resulting from the use of sugar, cream, and whole or skim milk; consequently the figures given in this example are simply to explain a procedure that is applicable to the use of other milk products, such as butter, condensed milk, etc., and are not intended to satisfy the particular requirement of 6.5 per cent, which may vary according to the milk-solids-not-fat content of the skim milk.

METHOD OF CALCULATING THE INGREDIENTS.

The calculations necessary in determining the proportions of the ingredients to be used are as follows (consider the ingredients as they are listed):

Sugar.—The amount of sugar is the same as the amount calculated for the mix, since there is no cane sugar in the other ingredients.

Cream (28 per cent).—The 150 pounds of 28 per cent cream does not contain more fat than is needed; hence the entire amount can be used.

Cream (43 per cent).—The amount of 43 per cent cream can be determined by subtracting the amount of fat added by the 150 pounds of 28 per cent cream from the total amount required and dividing the remainder by 0.43, thus:

$$253.77-42=211.77.$$
$$211.77\div0.43=492.5 \text{ pounds of 43 per cent cream.}$$

Skim milk.—From this ingredient will come the remainder of the constituents (milk solids not fat) of the mix. The amount required will be the difference between the amount of ingredients already used and the total (1,750) pounds required. For instance, $1{,}750-(245+150+492.5)=862.5$ pounds of skim milk.

EXAMPLE 2.

Give the proportions for 500 gallons of ice cream testing approximately 14.5 per cent fat, 13 per cent sugar, 9 per cent milk solids not fat, and 0.5 per cent gelatin. The weight of the ice cream desired is 5 pounds per gallon.

Stock on hand: Sugar; gelatin; 342 pounds of 30.5 per cent cream; 1,608 pounds of 38 per cent cream; 720 pounds of sweetened condensed milk containing 8.2 per cent fat, 42 per cent sugar, and 21 per cent milk solids not fat; and skim-milk powder.

TABLE 2.—*Illustration of Example 2.*

Total pounds desired, 5×500=2,500.	Ingredients and composition.	Constituents furnished.			
		Fat (14.5 per cent, 362.5 pounds).	Sugar (13 per cent, 325 pounds).	Milk solids not fat (9 per cent, 225 pounds).	Gelatin (0.5 per cent, 12.5 pounds).
Pounds.		*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*
23.0	Granulated sugar	.....	23.0	.....	.....
12.5	Gelatin (powdered)	.....	.....	.....	12.5
342.0	Cream, 30.5 per cent	104.3	.....	22.0	.....
524.0	Cream, 38 per cent	199.0	.....	30.0	.....
720.0	Condensed milk 8.2 per cent fat, 42 per cent sugar, 21 per cent milk solids not fat	59.0	302.0	151.0	.....
23.0	Skim-milk powder	.....	.....	22.0	.....
855.5	Water	.....	.....	.....	.....
2,500.0		362.3	325.0	225.0	12.5

METHOD OF CALCULATING THE INGREDIENTS.

The calculations necessary in determining the proportions are as follows (consider the ingredients as they are listed):

Granulated sugar.—The amount of granulated sugar can not be determined until the sweetened condensed milk is proportioned.

Gelatin (powder).—The amount of gelatin is the same as that calculated for the mix.

Cream.—The 342 pounds of 30.5 per cent cream does not contain more than a small proportion of the fat required; hence the entire amount can be used.

The amount of 38 per cent cream required can not be proportioned until after the condensed milk is proportioned, since the latter contains 8.2 per cent fat.

Sweetened condensed milk.—The amount of sweetened condensed milk that can be used is limited by the amount of sugar and milk solids not fat it adds to the mix. The 720 pounds of sweetened condensed milk will add only 302 pounds of sugar and 151 pounds of milk solids not fat; hence the entire amount can be used.

Granulated sugar.—With the condensed milk proportioned, the amount of granulated sugar necessary can be determined by subtracting the amount added in the condensed milk from the total amount required, thus:

$$325-302=23 \text{ pounds of granulated sugar.}$$

Cream (38 per cent).—Now that the condensed milk is proportioned, the amount of 38 per cent cream may also be determined. The amount is obtained by subtracting the sum of the fat contained in the 342 pounds of 30.5 per cent cream and the 720 pounds of 8.2 per cent condensed milk from the total amount required and dividing the remainder by 0.38, thus:

$$362.5-(104.3+59.0)=199.2.$$
$$199.2\div 0.38=524 \text{ pounds of 38 per cent cream.}$$

Skim-milk powder.—From this ingredient must come the remainder of the milk solids not fat needed in the mix. This is determined

by the difference between the sum of the milk solids not fat added by the cream[2] and condensed milk and the total amount required plus 5 per cent.[3] For instance:

$$225-(22+30+151)=22.$$
$$22+(0.05\times 22)=23.1.$$

Water.—The required amount of solid constituents having been provided, the amount of water needed will be the difference between the total amount of mix required and the sum of the ingredients used.

The accuracy of the calculations can be ascertained by comparing the sum of the figures in each column with the stipulated amounts placed at the top of each column.

When this is done, the ingredients are proportioned by careful weighing. The mix is then ready to be pasteurized and homogenized.

EXAMPLE 3.

Give the proportions for 350 gallons of frozen product testing approximately 9 per cent fat, 14 per cent sugar, 12 per cent milk solids not fat, and 0.5 per cent gelatin. The weight of the product desired is 5 pounds per gallon.

Stock on hand: Sugar; gelatin; 150 pounds of 28 per cent cream, 480 pounds of 34 per cent cream; skim milk; and 900 pounds of condensed skim milk, unsweetened.

TABLE 3.—*Illustration of Example 3.*

Total pounds desired, 1,750.	Ingredients and composition.	Constituents furnished.			
		Fat (9 per cent, 157.6 pounds).	Sugar (14 per cent, 245 pounds).	Milk solids not fat (12 per cent, 210 pounds).	Gelatin (0.5 per cent, 8.75 pounds).
Pounds.		*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*
245.0	Cane sugar		245		
87.5	Gelatin solution, 10 per cent				8.75
150.0	Cream, 28 per cent	42.0		10.0	
340.0	Cream, 34 per cent	115.6		20.8	
397.0	Skim milk, 9 per cent			35.8	
530.0	Condensed skim milk, 27 per cent			143.0	
1,749.5		157.6	245	209.6	8.75

METHOD OF CALCULATING THE INGREDIENTS.

The calculations necessary in determining the proportions are as follows (consider the ingredients as they are listed):

Sugar.—The amount of sugar is the same as the amount calculated for the mix, since there is no cane sugar in the other ingredients.

Gelatin.—The amount of gelatin solution is determined by moving the decimal point one place to the right, since the solution is a 10 per cent mixture.

[2] The amount of milk solids not fat in the cream is determined by multiplying the difference between the amount of cream used and the amount of fat it contains by 0.093 (the amount of milk solids not fat in the milk serum).

[3] Skim-milk powder contains on an average 3.5 per cent moisture and 1.5 per cent fat; consequently an allowance of 5 per cent is made in balancing the milk solids not fat.

Cream.—The 150 pounds of 28 per cent cream does not contain more fat than is needed; hence the entire amount can be used.

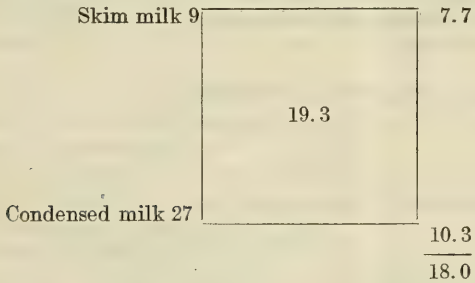
The amount of 34 per cent cream can be determined by subtracting the amount of fat added by the 150 pounds of 28 per cent cream from the total amount required and dividing the remainder by 0.34, thus:

$157.5 - 42 = 115.5.$
$115.5 \div 0.34 = 340$ pounds of 34 per cent cream.

Skim milk and condensed skim milk.—From these two ingredients must come the balance of the constituents (milk solids not fat) of the mix. To find the proportions subtract the sum of the milk solids not fat in the cream from the total amount required and divide by 927.5, the difference between the amount of ingredients already used and the total (1,750) pounds required. For instance:

$210 - (10 + 20.8) = 179.2.$
$(179.2 \div 927.5) \times 100 = 19.3$ per cent solids.

This gives the per cent of solids not fat that the additional 927.5 pounds of mix must contain. To find the proportion of skim milk and condensed skim milk necessary, the "square method" is used. The calculations for the square method [4] are as follows:



$927.5 \div 18 = 51.53$ number of unit portions in total mix.
$51.53 \times 7.7 = 396.78$ pounds of skim milk in total mix.
$51.53 \times 10.3 = 530.75$ pounds of condensed skim milk in total mix.

The accuracy of the calculation can be ascertained by comparing the sum of the figures in each column with the stipulated amounts placed at the top of each column.

When this is done, the ingredients are proportioned by careful weighing. The mix is then ready to be pasteurized and homogenized.

[4] The square method, sometimes called the Pearson method, may be used to find the proportion of milk and cream necessary in standardizing either the fat or the milk solids not fat in milk and cream. The purpose of the square is to separate the three principal factors in making the calculations, and to keep the deductions straight after the calculations have been made. For instance, in this particular problem, which is to find the proportion of skim milk and condensed skim milk necessary in making 927.5 pounds of skim milk containing 19.3 per cent milk solids not fat, the three principal factors are: First, the milk solids not fat content desired in the mixture; second, the milk solids not fat content of the skim milk; and third, the milk solids not fat content of the condensed skim milk. The first factor (19.3 per cent) is placed in the center of the square; and the other two factors (9 per cent and 27 per cent) are assigned to the corners on the left-hand side of the square. When this has been done, two calculations are made and placed as follows: (1) The difference between the upper left-hand figure (9) and the center figure (19.3), which is 10.3, is placed in the lower right-hand corner of the square, and indicates the number of pounds in a unit portion of the condensed skim milk required in the proposed mixture. Similarly the difference between the lower left-hand figure (27) and the center figure (19.3) which is 7.7, is placed in the upper right-hand corner of the square, and indicates the number of pounds in a unit portion of the skim milk required in the proposed mixture. Having ascertained the weight of one unit portion of each of these ingredients, any quantity of the desired mixture can easily be made by adding these two together to find the weight of one unit portion of the mixture desired, and then multiplying this by the number of unit portions in the total mix, as shown in the above example. The same procedure is used in standardizing the fat contents of milk and cream.

EXAMPLE 4.

Give the proportions of the following ingredients necessary for 280 gallons of a frozen product testing approximately 10 per cent fat, 8 per cent sugar, and the equivalent of 6 per cent additional sugar in the form of maltose sugar sirup and corn sirup,[5] 10 per cent milk solids not fat, and 0.5 per cent gelatin. The weight of the product desired is 4.5 pounds per gallon.

Stock on hand: Sugar; gelatin; maltose sugar sirup and corn sirup; cream (221 pounds of 40 per cent, 80 pounds of 35 per cent, 82 pounds of 24 per cent, 78 pounds of 29.5 per cent, 64 pounds of 28 per cent, and 73 pounds of 19 per cent); sweetened condensed skim milk testing 25 per cent milk solids not fat and 40 per cent sugar; and skim milk powder.

TABLE 4.—*Illustration of Example 4.*

Total pounds desired, 1,260.	Ingredients and composition.	Constituents furnished.			
		Fat (10 per cent, 126 pounds).	Sugar (8 per cent, 101 pounds).	Milk solids not fat (10 per cent, 126 pounds).	Gelatin (0.5 per cent, 6.3 pounds).
Pounds.		*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*
	Granulated sugar (cane)	.....	.....	.....	.....
63.0	Gelatin solution, 10 per cent	.....	.....	.....	6.3
151.0	Sirup, 80 per cent solids [1]	.....	.....	.....	.....
80.0	Cream, 35 per cent	28.0	.....		
82.0	Cream, 24 per cent	19.6	.....		
78.0	Cream, 29.5 per cent	23.0	.....	28.8	.....
64.0	Cream, 28 per cent	17.9	.....		
73.0	Cream, 19 per cent	13.8	.....		
59.0	Cream, 40 per cent	23.6	.....		
252.5	Condensed skim milk, 25 per cent solids and 40 per cent sugar	.....	101.0	63.0	.....
35.5	Skim-milk powder	.....	.....	34.0	.....
322.0	Water	.....	.....	.....	.....
1,260.0		125.9	101.0	125.8	6.3

[1] The solids in the sirup weigh about 121 pounds.

METHOD OF CALCULATING THE INGREDIENTS.

The calculations necessary in determining the proportions are as follows (consider the ingredients as they are listed):

Granulated sugar.—The amount of granulated sugar can not be determined until the sweetened condensed milk is proportioned.

Gelatin.—The amount of gelatin solution is determined, as in Example 3, by moving the decimal point one place to the right, since the solution contains 10 per cent of gelatin.

Sirups.—The amount of sirup is determined by multiplying 1,260 by the per cent desired, thus:

$$1{,}260 \times 0.12 = 151.2 \text{ pounds of sirup.}$$

Cream.—Since all the different lots of cream are used except the lot testing 40 per cent, the sum of the first five lots will add 102.3 pounds of fat to the mix and the remainder is determined by dividing

[5] Maltose sugar sirup and corn sirup are only half as sweet as cane sugar; consequently to replace the 6 per cent sugar it is necessary to use 12 per cent sirup.

the difference between 126 pounds and 102.3 pounds by the per cent of fat in the sixth lot, thus:

$$126.0-(28+19.6+23+17.9+13.8)=23.6.$$
$$23.6\div 0.40=59.0 \text{ pounds of 40 per cent cream.}$$

Sweetened condensed skim milk.—The amount of sweetened condensed skim milk that can be used is limited by the amount of sugar it will add to the mix. Dividing the amount of sugar needed in the mix by the per cent of sugar in the sweetened condensed skim milk will give the amount of this milk that can be used, thus:

$$101\div 0.40=252.5 \text{ pounds of sweetened condensed skim milk.}$$

Granulated sugar.—Since the required amount of sugar is added with the sweetened condensed milk, no granulated sugar is needed.

Skim-milk powder.—The amount of skim-milk powder is determined by subtracting the sum of the milk solids not fat added by the cream[6] and the condensed milk from the total amount required and adding 5 per cent,[7] thus:

$$126-(28.8+63)=34.2.$$
$$34.2+(34.2\times 0.05)=35.9.$$

Water.—The required amount of solid constituents having been added, the amount of water needed will be the difference between the total amount of the mix required and the sum of the ingredients used.

The accuracy of the calculations can be ascertained by comparing the sum of the figures in each column with the stipulated amounts placed at the top of each column.

When this has been done the ingredients are proportioned by careful weighing. The mix is then ready to be pasteurized and homogenized.

EXAMPLE 5.

Give the proportions for 220 gallons of a frozen product testing approximately 10 per cent fat, 14 per cent sugar, 10 per cent milk solids not fat, and 0.5 per cent gelatin. The weight of the product desired is 4.5 pounds per gallon.

Stock on hand: Sugar; gelatin; cream, 33 per cent; condensed milk testing 10 per cent fat and 22 per cent milk solids not fat; and whole milk testing 3.6 per cent fat.

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[6] The amount of milk solids not fat in the cream is determined by multiplying the difference between the amount of cream used and the amount of fat it contains by 0.093.

[7] Skim-milk powder contains, on an average, 3.5 per cent moisture and 1.5 per cent fat; consequently an allowance of 5 per cent is made in balancing the milk solids not fat.

TABLE 5.—*Illustration of Example 5.*

Total pounds desired, 4.5×220=990.	Ingredients and composition.	Constituents furnished.			
		Fat (10 per cent, 99 pounds).	Sugar (14 per cent, 138.5 pounds).	Milk solids not fat (10 per cent, 99 pounds).	Gelatin (0.5 per cent, 4.95 pounds).
Pounds.		*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*
138.5	Sugar	.....	138.5	.....	.....
49.5	Gelatin, 10 per cent	.....	.....	.....	4.95
185.0	Cream, 33 per cent	61.0	.....	44.9	.....
372.0	Whole milk, 3.6 per cent	13.4	.....		
245.0	Condensed milk, 10 per cent fat, 22 per cent milk solids not fat	24.5	.....	53.9	.....
990.0		98.9	138.5	98.8	4.95

METHOD OF CALCULATING THE INGREDIENTS.

The calculations necessary in determining the proportions are as follows (consider the ingredients as they are listed):

Sugar.—The amount of sugar is the same as the amount calculated for the mix, since there is no cane sugar in the other ingredients.

Gelatin.—The amount of gelatin solution is determined by moving the decimal point one place to the right, since the solution is a 10 per cent mixture.

Cream (33 per cent).—The amount of cream can not be proportioned until after the condensed milk is proportioned, since the latter contains 10 per cent fat.

Whole milk (3.6 per cent).—Temporarily omitted for the same reason.

Condensed milk.—The amount of condensed milk necessary in this case is determined by using a rough estimate (see p. 10). From this estimate it is found that 245 pounds is about the correct amount, thus:

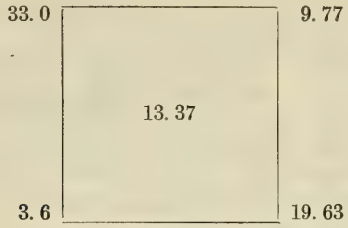
$$990-(138.5+49.5+245)=557.$$
$$557-(99-24.5)=482.5.$$
$$482.5\times 0.093=44.87.$$
$$44.87+53.9=98.77 \text{ pounds of milk solids not fat.}$$

Cream (33 per cent) and whole milk (3.6 per cent).—From these two ingredients must come the remainder of the constituents (fat and solids not fat) of the mix. To find the amount of each, subtract the amount of fat added by the condensed milk from the total amount required and divide by 557, the difference between the amount of ingredients already used, and the total (990) pounds required, thus:

$$99-24.5=74.5.$$
$$74.5\div 557\times 100=13.37 \text{ per cent in 557 pounds of milk.}$$

This gives the per cent of fat that the additional 557 pounds of mix must contain. To find the proportions of cream and whole milk that

are necessary, the square method [8] is used. The calculations for the square method are as follows:



29.40 total number of parts.

557÷29.4=18.94.
18.94×9.77=185 pounds of cream.
18.94×19.63=372 pounds of whole milk.

The accuracy of the calculations can be ascertained by comparing the sum of the figures in each column with the stipulated amounts placed at the top of each column.

When this has been done the ingredients are proportioned by careful weighing. The mix is then ready to be pasteurized and homogenized.

ROUGH ESTIMATES FOR PROPORTIONING INGREDIENTS.

Whenever a mix is made from an unlimited quantity of condensed whole milk the amount of condensed milk required is determined by first making a rough estimate. For instance, in example 5, it is not known what part of the total amount of milk solids not fat of the mix must come from the condensed milk, so that what is thought to be about the right amount is tried. In this case the figure taken to begin with was 220 pounds. This figure is taken because from experience it is known that about 50 per cent of the milk solids not fat in the mix must come from the condensed milk. That quantity divided by 22 (the per cent of milk solids not fat in the condensed milk) shows that it will require about 220 pounds of the condensed milk. This amount would add 22 pounds of fat and 48.4 pounds of milk solids not fat to the milk.

To tell whether or not this is right simply take the difference between the total amount of ingredients already calculated (that is, the pounds of sugar, gelatin, and condensed milk) and the total weight of the mix, and subtract the difference between the fat used in the condensed milk and the total amount required to find the amount of milk serum. Then multiply this figure by 0.093 to get approximately the amount of milk solids not fat that will come from the milk and cream and the sum of the two will indicate whether the proportions are correct, thus:

990 − (138.5 + 49.5 + 220) = 582 pounds of milk and cream.
582 − (99 − 22) = 505 pounds of milk serum.
505 × 0.093 = 47 pounds of milk solids not fat from serum.
47 + 48.4 = 95.4 pounds of milk solids not fat in mix.

[8] See p. 6.

The total amount of milk solids not fat lacks about 3.35 pounds, so we increase the amount of condensed milk 25 pounds or to 245 pounds, which gives practically the right amount as shown in the table.

In case the quantity had been increased only 15 pounds the total amount of milk solids not fat would have been a trifle short of the amount desired. The amount of milk and cream is then calculated as heretofore explained.

ADJUSTMENT OF COMPOSITION.

After a mix has been made up it frequently happens that the percentage of fat and milk solids not fat in the mix is found to be not as desired. In such cases the composition of the mix can be easily changed to approximate the percentage desired by the addition of water, cream, skim milk, condensed milk, or powdered milk, depending on the nature of the adjustment to be made. Three common adjustments are briefly as follows:

1. CORRECTING A MIX LOW IN FAT.

(*a*) Size of original mix, 3,600 pounds.

(*b*) Desired composition of original mix, fat 12 per cent, sugar 15 per cent, gelatin 0.5 per cent.

(*c*) Fat test of original mix, 11.5 per cent.

(*d*) The difference is 0.5 per cent fat, indicating a shortage of 18 pounds of fat in the mix.

To correct the standardization with cream testing 34 per cent fat, together with sugar and gelatin, increase the size of the mix to 3,800 pounds and calculate the amount of each constituent that is needed in the new mix. Then the difference between the amount of constituents necessary for the new mix and the amounts contained in the original mix furnishes a basis for adjusting the percentage of each constituent desired in the mix. For instance, the difference is 42 pounds of fat, 30 pounds of sugar, and 1 pound of gelatin.

$3{,}800 \times 0.12 = 456$ pounds of fat.
$3{,}600 \times 0.115 = 414$ pounds of fat.
$456 - 414 = 42$ pounds of fat.

The remaining constituents are calculated for the 200 pounds of additional mix with the original percentages, thus:

$200 \times 0.15 = 30$ pounds sugar.
$200 \times 0.005 = 1$ pound gelatin.

The proportions of the additional ingredients necessary would, then, be as follows:

123.5	pounds of 34 per cent cream.
30	pounds of sugar.
10	pounds of 10 per cent gelatin solution.
36.5	pounds of skim milk.
200	pounds total additional mix.

2. CORRECTING A MIX HIGH IN FAT.

(*a*) Size of original mix, 3,600 pounds.

(*b*) Desired composition of original mix, fat 12 per cent, sugar 14 per cent, milk solids not fat 8 per cent, gelatin 0.5 per cent.

(*c*) Fat test of original mix, 13 per cent.

(*d*) The difference is 1 per cent fat, indicating an excess of 36 pounds of fat in the mix.

To correct the standardization with plain condensed (3–1) skim milk, sugar, etc., increase the size of the mix to 3,900 pounds and calculate the amount of each constituent that is needed in the new mix. The basis for adjustment is the same as before, i. e., the difference between the amounts of the respective constituents necessary for the new mix and the amounts contained in the original mix. For instance, the difference is 0 pounds of fat, 42 pounds sugar, 24 pounds milk solids not fat, and 1.5 pounds gelatin.

$3{,}900 \times 0.12 = 468$ pounds of fat.
$3{,}600 \times 0.13 = 468$ pounds of fat.
$300 \times 0.14 = 42$ pounds of sugar.
$300 \times 0.08 = 24$ pounds of milk solids not fat.
$300 \times 0.005 = 1.5$ pounds of gelatin.

The proportion of the additional ingredients necessary would, then, be:

42 pounds sugar.
92 pounds condensed skim milk.
15 pounds 10 per cent gelatin solution.
151 pounds water.

300 pounds total additional mix.

3. CORRECTING A MIX LOW IN BOTH FAT AND MILK SOLIDS NOT FAT.

(*a*) Size of original mix, 3,600 pounds.

(*b*) Desired composition of original mix: Fat 12 per cent, sugar 13 per cent, milk solids not fat 10 per cent, gelatin 0.5 per cent, total solids 35.5 per cent.

(*c*) Fat test of original mix, 11 per cent.

(*d*) Total solid determination, 33.5 per cent.

(*e*) The difference in fat is 1 per cent, or a shortage of 36 pounds of fat.

(*f*) The difference in total solids is 2 per cent, but since the fat is 1 per cent lower than desired, it indicates that the solids other than the fat are 1 per cent too low.

(*g*) The amount of sugar added is then verified by checking the figures, and if these are found correct the difference of 1 per cent in total solids is attributed to a shortage of milk solids not fat.

To correct the standardization with 34 per cent cream, skim-milk powder, sugar, etc., increase the size of the mix to 4,000 pounds and proceed as explained in cases 1 and 2. The difference will be 84 pounds fat, 52 pounds sugar, 76 pounds milk solids not fat, and 2 pounds gelatin.

$4{,}000 \times 0.12 = 480$ pounds of fat.
$3{,}600 \times 0.11 = 396$ pounds of fat.
$480 - 396 = 84$ pounds of fat.
$400 \times 0.13 = 52$ pounds of sugar.
$4{,}000 \times 0.10 = 400$ pounds of milk solids not fat.
$3{,}600 \times 0.09 = 324$ pounds of milk solids not fat.
$400 - 324 = 76$ pounds of milk solids not fat.
$400 \times 0.005 = 2$ pounds of gelatin.

The proportion of additional ingredients necessary would, then, be:

247 pounds 34 per cent cream.
52 pounds sugar.
63 pounds skim-milk powder.
20 pounds 10 per cent gelatin solution.
18 pounds water.

400 pounds total additional mix.

The increase made in the size of the mixes is a matter that depends on the kind and composition of the ingredients used in making the adjustment and is usually kept as low as possible.

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THE MARKETING OF MILL FEEDS.

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Much has been written about nutritive values of various feeding stuffs and the popular method of arriving at them, but comparatively little is known by the average consumer about the merchandising of feedstuffs, or about what happens to a car of feed from the time it is sold by the manufacturer or miller until it finally reaches the retailer. A thorough understanding of the various phases of feed marketing would enable the dairyman to purchase his feed more advantageously and at the same time would place him in a position to determine with little effort approximately what prices he should pay for straight feeds delivered at his station.

It has been estimated that there are at least 3,000 feed jobbers in the United States. The number of retail dealers engaged in the feed-distributing business is conjectural, but a survey made during 1918 disclosed that approximately 15,000 firms handled feedstuffs in the northeastern section of the country, comprising the States of Pennsylvania, New York, New Jersey, Delaware, Massachusetts, Maine, Rhode Island, New Hampshire, Connecticut, and Vermont. Many of these firms, of course, handled feeds only as a side line.

According to figures published by the Bureau of the Census, the farmers' feed bill for 1919 was $1,097,452,187. Millions of tons of by-products of mills which formerly were allowed to go to waste are now utilized in the manufacture of mixed feeds, or are sold straight, enabling the dairy farmer to supplement locally produced grains or to balance his own rations.

Of the straight feeds, wheat feeds, which on an average selling price of $50 per ton during the year 1920 represented a value of approximately $200,000,000, are no doubt the most important item, and to avoid confusion the marketing of these feeds has been selected for

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discussion. These feeds are commonly known as "offal," and approximately 9,000 tons are produced from every 1,000,000 bushels of wheat milled.

The feed value of these by-products was not realized in this country to any extent 40 years ago. Their popularity has steadily increased, and while formerly they were principally used by farmers in the vicinity of the source of supply as a supplement to the home-grown ration, they are now shipped from important milling centers to practically every section of the country.

The requirements of feeders in Pacific coast States are largely supplied by local mills and are supplemented by the surplus of mills located in neighboring States. The production of local mills in the Central West and the Northeastern and Southeastern States of the country is insufficient to supply the enormous demand from the dairy interests in those sections. To bridge the gap large quantities are obtained from western mills, principally from those located in Minnesota, Kansas, Missouri, Nebraska, and the Dakotas. The movement to the Gulf States is usually not very heavy. At times, however, there is a very active demand from Texas, which is mainly supplied by Kansas and Oklahoma mills.

While the handling of wheat feeds differs in some respects from that of other commodities, they reach the ultimate consumer through a system of distribution similar to that used for other food and feedstuffs, in which various middlemen, such as brokers, jobbers, commission men, and wholesale and retail dealers, play a very important part.

HOW FEEDS ARE SOLD BY MILLS.

The distribution of mill feeds from the larger mills to consumers is generally performed by the jobber, broker, commission merchant, wholesale dealer, and retail dealer. Of course, the route from producer to consumer varies. For example, brokers in distributing markets sell at times direct to dairy farmers, and jobbers in milling sections may sell occasionally to cooperative associations direct. Such instances are rare, however.

The production of country mills when not of great volume is often sold entirely to local feeders or in neighboring territory in ton lots or less. If there is any surplus the intermediary services of middlemen are used. (Fig. 1.)

Direct sales by mills.—While the bulk of wheat-feed production by flour mills is handled through middlemen, fair quantities are sold to mixed-feed plants, farmers' cooperative purchasing organizations, and neighboring dairy farmers direct. The volume of sales to distant dairy farmers is negligible, for farmers do not like to pay for shipments on "sight-draft" basis. On the other hand, mills do not seem to be anxious to increase their direct sales to distant dairy farmers, because jobbers and other intermediaries offer a ready and never-failing outlet for their by-products, and because the present system of distribution appears to them the most economical in the long run.

Sales to local jobbers and brokers.—Contrary to the general belief, the principal mills do not sell extensively to country dealers direct. Flour mills in Minneapolis, Kansas City, St. Louis, and other important markets dispose of enormous quantities of their wheat by-

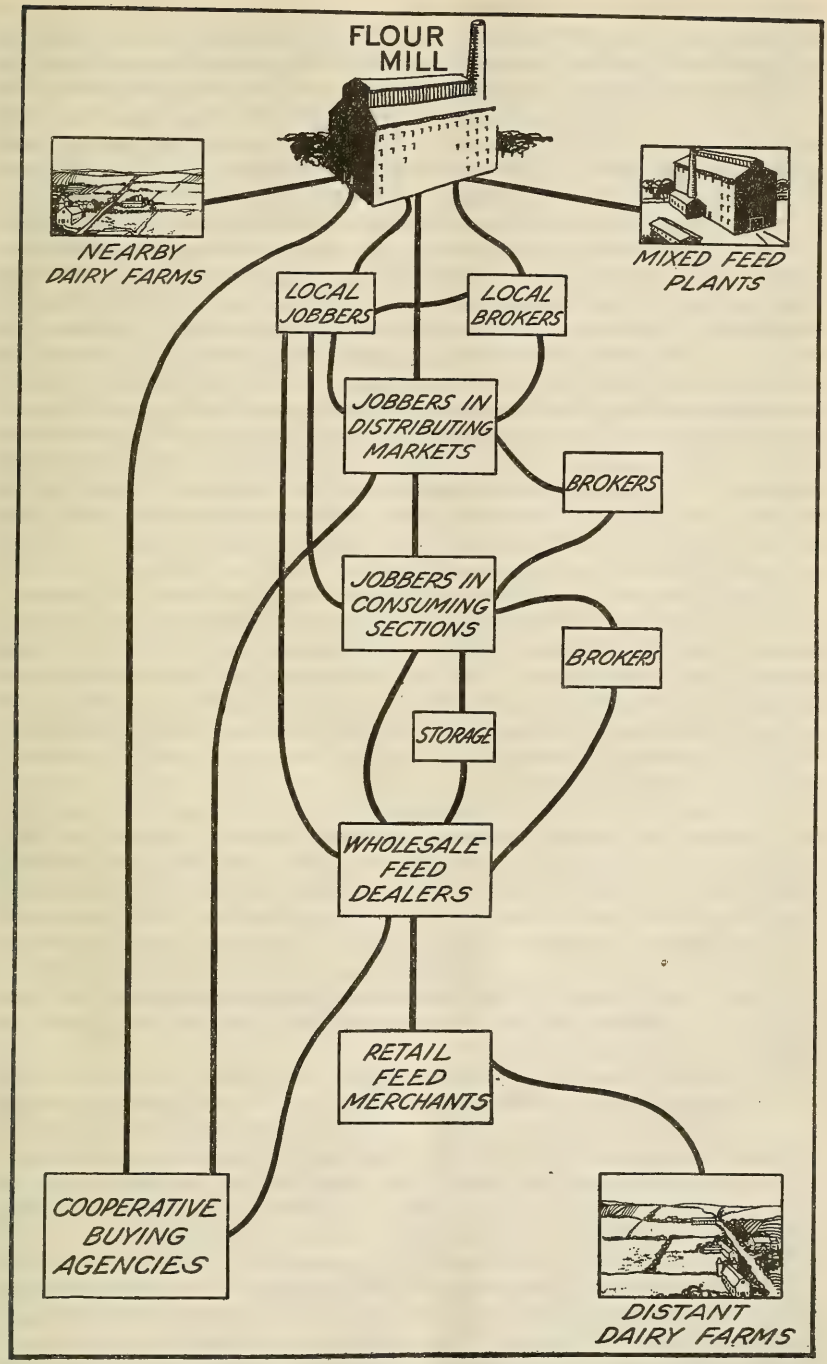

FIG. 1.—Chart showing system of distribution of mill feed from flour mill to consumer.

products through brokers and to local jobbers. The latter, with few exceptions, do not confine their activities to a strictly merchandising business, but frequently resort to short selling when the outlook for a declining market is favorable, or they contract for heavy supplies for future shipment when they expect that the usual good demand during the heavy feeding season will enable them to dispose of such purchases at a profit. The fact that the majority of these jobbers manage to remain in business would indicate that their judgment in anticipating future feed-marketing conditions is fairly accurate.

Sales to jobbers in distributing markets.—If better prices are obtainable by the mills elsewhere, their offerings are placed through their brokers or representatives before the jobbers in the principal distributing markets. These jobbers in turn either utilize the services of brokers in markets in consuming sections in order to resell to other jobbers or wholesale dealers, or they dispose of their holdings to country dealers through salesmen or through the use of offerings sheets. Frequently sales are made by one jobber to another jobber in the same market. This is particularly true of transit offerings. In case the jobber who owns the shipment "on rails" is unable to find a buyer for it he may be obliged to discount the prevailing price in order to make the sale to some other jobber who may have one or more open orders on hand.

Shipped to markets to be sold on commission basis.—In several sections of the United States the handling of wheat feeds on a commission basis has worked out to the mutual satisfaction of both the mills and the buyers. The only serious objection mills have to this method is that some commission men may indulge in selling to phantom concerns, or those in which they are financially interested, with the purpose of reselling at higher prices to bona fide dealers, perhaps on the same day.

Considerable quantities of wheat feeds are handled on a commission basis in Pacific coast markets. Firms to whom a car of feed has been consigned allow shippers to draw on them for 60 to 80 per cent of the value of the shipment and when notified of its arrival arrange for storage if it has not been sold in the meantime. The goods are then disposed of as promptly as possible. They may be sold in lots or the entire contents of a car may be sold to one buyer, usually basis spot f. o. b. warehouse. Many of these commission men are not in a position to make delivery; hence prices delivered buyer's place of business are not often quoted.

The most businesslike commission men give prompt notice of sale to the shipping mill. When a trade is made it is their duty on the day of the trade to send a written confirmation to each of the principals (to the buyer a confirmation of sale and to the seller a confirmation of purchase), setting forth the specifications of the trade as made by him. As soon as payment is received account sales should be rendered, accompanied by check for the net proceeds.

It should be clearly understood by commission men that in case goods have been consigned to them to be disposed of on a commission basis, the shipper is entitled to receive the full amount realized, less interest and storage charges, if any, and the commission agreed upon. Every effort should be exercised by them to protect the interest of their principals and to obtain the best possible price.

It often happens that shippers are advised, either by telephone or telegram, that a certain price per ton can be realized for their shipment, and after obtaining consent to sell at that price the shipment is immediately sold at a higher quotation. The shipper may or may not receive more than the price which he had said would be satisfactory to him. Frequently he does not. This practice, while not general, unfortunately is indulged in with too great frequency, and steps should be taken by the trade and exchanges to abolish it, because it is inimical to their interests and those of bona fide dealers.

Sales to self-owned concerns or those in which the commission man may have an interest, or concerns solely established for the purpose of having shipments booked to them temporarily, at prices not fully representing prevailing market values, with the intent to sell immediately at higher prices, should not be permitted.

The handling of wheat feeds in distributing markets.—Jobbers in distributing markets differ from jobbers in producing markets in their methods of handling wheat feeds. The latter, while they have the option of placing shipments in transit unsold when tender is made by mills on contract, do not follow this method to the same extent as jobbers in the heavy consuming sections. They generally prefer to make sales through brokers or direct to jobbers in distributing markets in principal dairy sections.

A large volume of the business of jobbers or wholesale dealers in distributing markets is done "on rails." When it becomes necessary for the jobber or wholesale dealer to furnish billing instructions for the stuff he has contracted, and transit offerings are heavy, he will, particularly during times of light demand, order shipments direct to destination according to his open orders on file.

If he has no open orders on file he has the option of reselling to another jobber, of placing the feed in storage, or of placing the shipment in transit to be held at a designated point for orders.

In the more important feed-consuming sections facilities are extended by the railroad companies whereby shipments may be billed to so-called holding or diversion points, from which shipments may be reconsigned at the through freight rate. A diversion charge is assessed for this privilege and demurrage charges are assessed if the car is held beyond the free-time period.

If the jobber, therefore, has no open orders on file, he often orders his shipments to such holding points with the view of disposing of them prior to their arrival at such points. He may select a holding point close to the point of shipment or one located in the section in which the bulk of his business is transacted, depending upon prevailing conditions.

In the selection of the holding point the jobber is not restricted to one located in the territory as indicated by the rate-basing point shown on the contract and on which basis the sale was consummated. In the northeastern section, for instance, it is a well-established rule that in all delivered sales to any of the following trunk-line terminal points—Boston, New York, Philadelphia, and Baltimore—the point specified shall be considered as a rate basis only and not necessarily the final destination of the goods, and that shipment shall be made to any point and via any line open for business in the eastern trunk line territory designated by the buyer which is reached by lake or

lake-and-rail lines during the season of navigation, or by all-rail trunk lines at other times, at the differential in effect at the time of shipment, as shown by published tariff rates, provided shipment is made within contract time.

Depending upon the demand for feeds and prevailing prices, shipments are ordered out over either fast or slow routes. When slow movement is desired the jobber may choose to order his cars over the most circuitous route and preferably over roads on which congestions have been reported, while if quick dispatch is wanted he can select any of the numerous fast freight lines. When ordering shipments to holding points the jobber assumes the risk of being obliged to pay diversion and demurrage charges at such points should he be unable to dispose of the shipments. To keep cars at holding points is an expensive proposition, therefore, transit offerings are often quoted at less than shipment prices. On the other hand, a spontaneous demand frequently results in such offerings commanding a premium of 50 cents or $1 per ton over shipment prices.

It should be understood that the arrival of a car at a holding point does not necessarily mean that it then becomes necessary for the dealer to dispose of it immediately at prevailing or sacrifice prices. There are often other avenues open to him, one of which is the ordering of the car to some other holding point along the route, or he may deem it advisable, if offerings are heavy and the demand poor, to place the shipment in either a private or railroad storage warehouse, a large number of which have arrangements allowing the reshipping of stored feeds at the through freight rate.

The principal reason for placing cars in transit unsold is that jobbers are often unable to obtain orders for goods previously bought from mills in anticipation of higher markets and therefore are unable to furnish instructions ordering these shipments direct to destination. Moreover, should the jobber fail to furnish specifications as required under the rules of the contract, the mill may elect to resell the goods in the open market, and in the event the market price is lower than the contract price he would be required to pay the difference in price.

In case the market is in the buyer's favor and the seller exercises his right to cancel the contract because shipping instructions are not supplied, the buyer is not entitled to anything. Before canceling the contract or reselling the goods, however, the seller is obliged to give the buyer due notice of his intention to do so.

Rather than allow the resale at whatever price the seller may be able to realize, the buyer usually prefers to take chances on the course of the market and his ability to dispose of the goods in his own territory and at his own price.

The practice of placing considerable quantities of feeds in transit, unsold, so common in the Northeast, is not followed to the same extent in other sections. The more constant and heavier demand in Northeastern States affords dealers a readier outlet than is found in other regions. In several sections the practice of holding cars in transit is rarely followed.

The territory supplied by distributors is confined to certain well-defined sections or States. For instance, dealers in Pittsburgh, Phila-

delphia, and Buffalo, who, with the Boston and New York City trade, supply the bulk of requirements of the Northeastern States, rarely make sales in the Southeast, while dealers in the latter territory located in such markets as Atlanta, Savannah, Augusta, Birmingham, and Montgomery seldom solicit business in Louisiana and Texas.

In fact, in practically every State where locally produced wheat feeds are insufficient to supply local requirements there are one or more important markets where such feeds, obtained by dealers from the large milling centers or interior mills, may be obtained by country dealers or dairymen.

It is customary at times to place shipments in transit unsold, particularly when the demand is good and is equal to or in excess of offerings. In such cases the jobber usually has a number of unfilled orders on hand on which these shipments may be applied in the event the demand should fall off and he should not succeed in finding buyers for them. This accounts for the desire on the part of jobbers to keep always well sold up ahead, often for a considerable period.

Open orders for future shipment can not be filled until due. The jobber will not apply transit shipments in case premiums can be realized for transit over shipment prices. He will not usually fill such open orders, particularly those for season shipment, until a more opportune time arrives. This practice has led to some criticism at times, and it is claimed that the desire to keep well sold up ahead has a tendency to hold up prices artificially.

When sales are made during declining markets at higher than prevailing prices, the desire of jobbers to gain a few extra dollars per ton because of the possibility of buying cheaper later on, rather than to cater to the immediate wants of the buyer, has often led to great inconvenience on the part of the buyer. This, in a measure, explains the growing tendency of country feed dealers to purchase transit cars rather than future delivery shipments, and when badly in need of feedstuffs they prefer to buy shipments actually at holding points rather than those reported as being en route to such points. While both offerings are considered transit shipments, the approximate date of arrival at final destination of cars actually at holding points may be readily estimated, while on those shipments for which so-called advance notices have been given it is exceedingly difficult to determine at times when delivery will be effected, as various factors, such as tie-ups, congestions, etc., may tend to delay them.

STORAGE OF WHEAT FEEDS.

During the late summer months, when pasturage is ample and wheat moves to the big milling centers in large volume, the offerings of wheat feeds by mills are usually very heavy and much feed is booked for deferred shipment.

At this time of the year the large jobbers and wholesale dealers anticipate their requirements for the coming winter and early spring. On account of the conditions named, prices of feed are often low during that season, and the jobbing trade naturally takes advantage of this situation.

Billing instructions on future shipment contracts do not have to be furnished until they are requested by the mills, which is usually some time during the month in which it is contracted to make shipment. Often, when the mills are in a position to do so, extension of time is given. On the other hand, if the mill is unable to fill the contract within contract time, the jobber or dealer frequently extends the same courtesy and allows shipment to be made at a later date than was originally agreed upon. The generally observed rule covering the period allowed for the furnishing of directions is that, unless otherwise agreed, all sales are understood to be for shipment at seller's option and that specifications on sales for immediate or quick shipment must be furnished at the time the transaction is closed. On sales for prompt shipment such specifications must be furnished within 3 days from date of the transaction. On sales for a longer period specifications must be furnished by the buyer within 3 days after demand by seller, and in any event at least 10 days prior to expiration of the contract, whether such specifications have been demanded by seller or not.

As has been pointed out, the open orders on file with the jobber or wholesale dealer are filled direct in case conditions do not warrant the shipping of cars to holding points to be held for orders. In case the demand for transit shipment is poor and no immediate improvement in conditions is expected, arrangements are usually made to have the shipments placed in storage warehouses, many of which are situated in eastern and western lake ports and large terminal markets.

While storing is resorted to at times to avoid breaks in prices, such facilities are mainly used with the expectation that during the fall, winter, and early spring materially higher prices may be realized because of the increased demand during such periods for feedstuffs generally and because of the demands of the jobbers' trade during that period.

In case storage is contemplated, arrangements should be made in due time to enable carriers and owners of warehouses to make the proper reservation. If such matters are taken up at the last moment it frequently happens that because all available space has been allotted no further requests can be entertained.

The rates charged for loading and unloading, as well as storage charges of railroad warehouses at lake ports, are those in effect at time of unloading as per tariffs on file with the Interstate Commerce Commission. The handling and storage charges of private warehouses are usually higher.

The storage charges, as a rule, do not cover insurance, which must be provided by the holder. The insurance rate is comparatively low, as most warehouses have up-to-date fire protection. Policies may be written for individual shipments or one policy may take care of all goods in certain warehouses in one city to the extent of their declared value. The amount of the policy may be reduced from time to time at the option of the insured, according to the value of the goods shipped out of the warehouses. Not all of the warehouses offering facilities for the storing of feeds have agreements with carriers allowing the reshipping of such feeds at the through rate from point of shipment to final destination. To avoid payment of

local rates of freight from cities where such warehouses are situated to final destinations, it is important that this feature be looked into before storage arrangements are made.

Freight charges on stored shipments to point where stored are collectible at time of storing, the balance being billed forward when the shipment is ordered out to its final destination. Storage charges are payable monthly.

HANDLING OF FEEDSTUFFS BY COOPERATIVE SOCIETIES.

In line with everything else, the overhead expenses of middlemen have grown to such an extent that unless a substantial margin of profit is added to their cost price it is impossible for them to conduct their business on a paying basis. This, in a measure, explains why the retail selling price of feedstuffs during the last few years advanced more than the increase in price received by the manufacturer seemed to warrant. The difference between mill and retail prices at present often amounts to as much as $10 per ton, exclusive of freight charges.

Largely because of this wide variation in prices and because it was thought in some communities that the service performed by the local dealer was not altogether satisfactory, a large number of cooperative buying organizations have undertaken to purchase the feed requirements of their members collectively.

The feeds are generally retailed by the societies to the farmer at the prevailing market prices and the accumulated profits are distributed annually on a pro rata basis, according to the amount of the purchases of the individual member, or according to the number of shares held in the organization by each farmer.

At first, purchases by cooperative societies were made largely from wholesale dealers and jobbers in neighboring markets because of the practice of these merchants to sell on "arrival draft" basis, which enabled the manager of the organization to inspect contents of car before payment was made. Shipping mills required the payment of drafts covering their shipments "at sight," and because of the fear that difficulty would be encountered with claims for damage filed after payment for the goods had been made, few orders were placed with mills. Since it has been the experience of these associations that all just claims are receiving due consideration and are usually promptly disposed of, this objection has largely disappeared and business between cooperative societies and shipping mills has increased substantially.

With the growing tendency on the part of consumers and farmers' organizations to buy their feedstuffs cooperatively, it is essential that they understand trading rules fully, and that they have a clear idea about the definitions of the various kinds and classes of feeds.

TRADE RULES.

In spite of the importance of the feed business there were until recently no generally recognized rules covering trades. Recently a number of exchanges and many important trade organizations have adopted the regulations formulated by a well-known feed distributors' association.

The following rules and customs are those most generally accepted by the trade. They differ slightly in a few respects from those observed in certain sections:

Confirmations.—Every trade or transaction in feedstuffs should be, and usually is, confirmed by the buyers and the sellers. If the trade has been negotiated by a broker, he should furnish both parties to the transaction with a confirmation stating fully terms and conditions of sale. Confirmations should be mailed or given on the date of sale and should be immediately checked and any discrepancies should be noted and brought to the attention of the other party to the contract. The confirmation should indicate the number of tons the car contracted for is to contain; if sacked, the number of sacks, kind used, and weight of each should be stated. The price shown should be either delivered destination, f. o. b. shipping point, or delivered to a certain rate-basing point or station. The time of shipment and terms of payment should be given.

Weights.—If instead of the number of tons the car is to contain the term "a carload" is used on the confirmation, it is generally understood to mean 20 tons net. A ton of feed weighs 2,000 pounds and a bag of feed, unless otherwise specified, 100 pounds. It should be understood that if rules of carriers provide for a higher minimum, or State laws are in conflict with generally recognized weights, transactions in feedstuffs are subject to such rules and laws.

Time of shipment.—The interpretations of rules covering time of shipment do not differ materially between the various sections of the country. There are slight differences of opinion at times as to whether the given number of days shall mean calendar days, excluding the date of sale, or from the day directions are received by the seller. The rules generally observed by the trade as to time of shipment are given below:

Immediate or rush shall mean shipment within 3 calendar days from the day directions are received by seller.

Quick shipment shall mean shipment within 5 calendar days from the day directions are received by seller.

Prompt shipment shall mean shipment within 10 calendar days from the day directions are received by seller.

Unspecified shipment.—Where shipment is not specified, prompt shipment is understood.

Loaded, spot, instant, or on track, shall mean that the goods are actually loaded and ready for billing, and the bill of lading must be dated on the day of sale.

In transit shall mean that the bill of lading must be dated at least one day prior to date of sale.

Deferred shipment.—In the purchase or sale of feed for deferred shipment the following specifications shall govern:

Where a specified number of days is not stated in the contract, but the time is referred to as first half or second half of a given month, it shall be understood that up to midnight of the 15th shall be considered the first half (this including February), the remainder of the month to be considered as second half.

Season shipments.—Season shipments shall mean shipment at any time, at the seller's option, between the date of sale and December 31 of the current year, inclusive.

The date of the bill of lading signed by the agent of the railroad issuing it is considered conclusive evidence of date of shipment in the absence of fraud. Exchange bills of lading show date of the original bill of lading, the name of the railroad, the station, and the agent who issued them. Any loss resulting through irregularity of the bill of lading is due from the seller.

Irregularities in bills of lading.—When an invoice covering the shipment contracted for is received and no irregularities are found in the bill of lading, payment of draft is made immediately if the shipment was bought "sight draft" basis. If bought on "arrival draft" basis and subject "inspection allowed," the draft is paid as soon as the car has arrived and contents have been inspected. The inspection should be performed promptly after notice of arrival is given by the railroad agent.

Delayed shipment.—If the seller fails to fill the contract within contract time the buyer has the right to extend the time or buy in for the seller's account, but prompt notice should be given to the seller of the buyer's intention to do so. The buyer has the same rights in the case of uncompleted contracts.

Arbitrations.—Space will not allow a discussion of the rules pertaining to weights, reshipment, claims, etc. In cases of dispute resulting from misunderstandings about these features, it is customary to refer them to the arbitration committee of the exchange or association of which one or both parties to the contract may be members. Friendly arbitrations are frequently resorted to. In the latter case each party to the contract selects a person or firm to represent him in the dispute and the two selected decide on the third member of the committee.

GRADES.

Wheat feeds are known under various names and terms in different parts of the country, but most commonly by the descriptions adopted by the Association of Feed Control Officials of the United States. Standards have been proposed by a committee of this association and are under consideration. In the absence of contrary arrangements, it is customary to accept the descriptions as promulgated by that organization, which are as follows:

Wheat bran.—Wheat bran is the coarse outer coating of the wheat kernel as separated from cleaned and scoured wheat in the usual process of commercial milling.

Standard middlings.—Standard middlings (red shorts or brown shorts) consists mostly of the fine particles of bran and of germ, with very little of the fibrous offal obtained from the "tail of the mill." This product must be obtained in the usual commercial process of milling.

Gray shorts.—Gray shorts (gray middlings or total shorts) consists of the fine particles of the outer bran, the inner or "bee-wing" bran, the germ, and the offal or fibrous material obtained from the "tail of the mill." The product must be obtained in the usual commercial process of flour milling.

Flour middlings.—Flour middlings consists of standard middlings and red dog flour combined in the proportions obtained in the usual process of milling.

White shorts or white middlings.—White shorts or white middlings consists of a small portion of the fine bran particles and of the germ and of a large portion of the fibrous offal obtained from the "tail of the mill." This product must be obtained in the usual process of flour milling.

Red dog flour.—Red dog flour consists of a mixture of low-grade flour, fine particles of bran, and the fibrous offal from the "tail of the mill."

Wheat mixed feed.—Wheat mixed feed (mill-run wheat bran) consists of pure wheat bran and the gray or total shorts or flour middlings combined in the proportions obtained in the usual process of commercial milling.

Wheat bran and standard middlings.—Wheat bran and standard middlings consists of the two commodities as defined above, mixed in the proportions obtained in the usual process of commercial milling.

Screenings.—Screenings consists of the smaller imperfect grains, weed seeds, and other foreign materials, having feeding value, separated in cleaning the grain.

Scourings.—Scourings consists of such portions of the cuticle, brush, white caps, dust, smut, and such other materials as are separated from the grain in the usual commercial process of scouring.

NOTE.—If to any of the wheat by-products feeds there are added screenings or scourings, as defined, either ground or unground, bolted or unbolted, such brand shall be so registered, labeled, and sold as clearly to indicate this fact. The words "screenings" or "scourings," as the case may be, shall appear as a part of the name or brand and shall be printed in type of the same size and face as the remainder of the brand name. When the word "screenings" appears it is not necessary to show also on the labeling the word "scourings."

As no definitions have been adopted for feeds, such as wheat chops and recleaned wheat screenings, samples should always be requested at time of purchase to avoid any controversies at time of delivery.

To avoid disputes, care should be exercised not to overstate or misrepresent qualities. When the demand is poor because of excellent pasturage conditions, or excessive supplies, salesmen often ascribe qualities to the feeds they offer which they may or may not possess. Frequently fancy names are used to describe straight feeds which should not be necessary if all feeds of the same kind were alike.

When trying to sell coarse spring bran, for instance, it is often termed "flakey," and the salesman does not ordinarily hesitate to designate his offerings as the product of one of the larger or better mills. The chances are that what he really has to sell is the coarse spring bran which his firm is able to obtain at the lowest possible price. Other wheat feeds are offered under descriptive terms which have no conventional meaning. The only meaning they may have is such as the sellers may or may not intend them to convey. Disappointment on the part of the buyer in not receiving the quality he expected to get usually follows and, particularly during the times of rapid declines in the market, is the chief cause of many refusals to accept. Such disappointment often leads to the loss of trade.

WHAT THE COUNTRY FEED DEALER SHOULD KNOW.

Practically every jobber and wholesale dealer in principal markets issues quotation sheets regularly, some with greater frequency than others. There is therefore no excuse for the country feed dealer not keeping posted relative to the prices of the more active feeds. In the case of feeds handled in comparatively small volume, such as red dog, flour middlings, oat feed, etc., the careful feed dealer obtains samples and quotations before placing his order because of the vast difference in quality and the wide range in prices at which such commodities are offered. If a country feed dealer does not receive any quotations and is in the market for a car of feed, he should write to four or five representative dealers in distributing centers, describing the kind of feed he desires, the approximate date it is wanted, size of car, railroad delivery, and further particulars, and request that delivered price be quoted and offerings be submitted. Upon receipt of offerings the buyer, by comparing prices and conditions, is in a position to determine which one best suits his needs. Prompt acceptance is essential.

To select a particular shipment from any of the quotation sheets he receives has at times proved to be an expensive proposition to the buyer. A combination of local rates may be assessed because the delivering carrier is not a participating carrier to the tariff under which the shipment moved. Jobbers and wholesale dealers are fairly familiar with traffic arrangements and do not knowingly apply on contracts those shipments that can not be handled at the through rate from point of shipment to destination. Nevertheless, instances have occurred where through an oversight buyers made an improper selection and sellers refused to make good the excess freight charges caused by the mistake, in spite of the fact that the buyer could not be expected to be familiar on the date the sale was made with the routing of the shipment as indicated on the bill of lading. The seller's view in such instances is an arbitrary one, as it is commonly understood that when a sale has been made on a delivered basis it is incumbent upon the seller to see that a shipment is applied on the contract which will make delivery at the flat through rate. In other words, the liability for all freight and other charges in such cases rests with the seller.

A knowledge of rules and regulations and of feeding values, particularly of compounded feeds, is as necessary to the successful conduct of the business of the country feed dealer as it is to that of other feed distributors. While literature pertaining to these features is readily obtainable, it is difficult for him to become familiar with certain undesirable practices, except through experience. Many of these practices, while not indulged in by reputable concerns, are committed frequently.

The most common experience, one that puzzles most country feed dealers, is that while on declining markets they find no difficulty in supplying their needs from offerings sheets of jobbers and wholesale dealers, a rising market often brings a statement that the particular offering desired by them has been purchased by some other dealer who wired in earlier that day.

There is really nothing unusual about this, as most of the offerings by jobbers and wholesale dealers are made subject to previous sale,

and acceptance to reach them before 10 or 10.30 a. m. of the day following date of issue of the quotations. This enables them to reject any acceptance if the market is stronger or has advanced, while if the market shows a weaker tendency or has declined the order will be filled.

If bran, for instance, is quoted at $25 per ton delivered, and because of a brisk demand brought on by unfavorable weather conditions in a certain section or other causes, a number of mills advance their prices 50 cents per ton, the country buyer, on receipt of his telegram by the jobber or wholesale dealer, is often advised that the particular car of bran he wanted has been sold, but that another one is available at $25.50. He may receive a telegram reading about like this:

> JNO. DOE, Zanesville, New York.
> Car bran due Sayre sold. Can book another car making your delivery at $25.50. Wire if accepted.
>
> CHARLES ROE.

If, because of generally favorable weather conditions or heavy production, mills reduced their prices 50 cents per ton, the country dealer, upon receipt of his wire, will be advised that his order has been booked, because the wholesaler or jobber is then in a position to replace the car at a lower figure than that prevailing on the date his quotation sheet was issued. This illustration does not represent an unusual case, but a typical one and one which happens only too frequently.

It is the duty of the country feed buyer to furnish proper shipping directions, and when he fails to do so such default relieves the seller of any obligation to make the shipment, and when other mutual terms of the contract have been violated by the buyer the seller has the right to cancel the contract or to resell the goods in the open market for the buyer's account. In the latter event the country feed dealer or buyer is liable to the seller if any loss is incurred. The seller should give the buyer prompt notice after the cancellation of the contract or the resale of the goods is made. In case of failure on the part of the seller to make shipment, the buyer may rescind either the contract or buy-in for the seller's account, in which case the seller is liable for the loss incurred by the buyer. Arrangements are often made between buyers and sellers to cancel contracts by paying the difference between the contract and the market price.

When shipping directions are furnished by the buyer before the expiration of the time allowance and the shipments are made by the seller before the buyer has given notice of his intention to exercise his option to cancel by paying the marginal difference, the shipment must be accepted.

Invoices received by buyers should always be carefully checked with the bill of lading and freight bills to detect possible errors. Unknowingly dealers sometimes have paid double freight charges on shipments consigned to them which would not have happened if proper care had been exercised, as overcharges due to misroutings or railroad errors are easily detected when invoices are properly audited.

That dealers should pay freight charges twice on the same shipment seems almost unbelievable, yet it is a fact that thousands of dollars in freight and other charges are annually paid by them for

which they are not liable. How this happens is not generally understood, but is easily explained.

The freight allowances on delivered shipments are customarily deducted from the seller's invoice, but as many shippers have understandings with transportation companies that all of their shipments are to be handled "freight to be prepaid," the invoices of shippers which have made such arrangements will show in the column on the invoice, used for the purpose of indicating the freight allowance, that no freight will be collected, i. e., "freight prepaid," and the gross amount of the invoice will be shown in the outer column and will be collected by draft.

Through the oversight of railroad employees many shipments are allowed to go forward "freight collect," although instructions from the shipper were to collect the freight from him. The result is that the buyer not only pays the freight when making payment of the gross amount of the invoice but he is also asked to pay freight to the railroad agent upon arrival of the shipment. It is, therefore, very important for the buyer to check carefully all invoices with his freight bills to avoid the double payment of freight charges. Charges that may have accrued while the shipment is in transit and that are due from the shipper, such as diversion and demurrage, will be found readily and claims for such items should be lodged with the seller as promptly as possible.

While familiarity with rules and definitions enables the country feed dealer to carry out the various operations incident to a transaction in feedstuffs, it does not necessarily qualify him to carry on his feed business successfully. He must study closely the conditions in the principal sources of supply, which may be thousands of miles away or may be close to the consuming section in which he is located. Frequently for many reasons requirements may be purchased in neighboring markets to better advantage than in distant producing markets. Particularly in cities or towns with more than one feed dealer and where there is more or less competition it is usually well worth while for dealers to acquaint themselves as fully as possible with prevailing conditions, such as supply, demand, and stocks on hand in distant markets.

HOW TO STUDY MARKET CONDITIONS.

The associative action of jobbers, brokers, and wholesale dealers has resulted in the formation of exchanges and trade organizations. One of the functions of these organizations is to collect and disseminate market prices and information, which makes it possible for the feed trade in the large shipping and distributing markets to keep posted relative to conditions affecting their business. Country dealers and cooperative societies, however, are not always in a position to avail themselves of the services of the exchanges and are largely dependent on the generally bullish ideas of visiting salesmen in forming their opinion of conditions.

A large number of trade journals devote space to the discussion of feedstuffs conditions in various markets. While no doubt much of the information is valuable, it has often been said that, as most of it is obtained from firms that specialize in the feeds they discuss,

the reports are more or less partial and are therefore not always dependable.

It is generally understood in what manner prices are determined in the most important shipping markets, but the prices quoted in newspapers in markets where no exchanges are located show at times such wide variations that for practical purposes they are useless. Little is known by the average dealer as to how they are arrived at or what they represent. Much remains to be done to educate buyers in this respect. A few of the principal difficulties leading to these wide ranges are here pointed out.

FACTORS CONTROLLING PRICES.

Prices for wheat feeds are controlled largely by potential supplies and production in surplus-producing sections. However, the availability of other feedstuffs which may be used as substitutes is an important factor. It is not uncommon in a section where liberal supplies of other feedstuffs are available to find prices of wheat feeds quoted materially lower than in sections where supplies are scant. This in spite of the fact that both sections may be the same distance from production centers. Not infrequently the prices for wheat feeds quoted by one local newspaper differ materially from those appearing in another newspaper published in the same city.

The main reason for this is that when feeds are not actively traded in the quotations published will be either those which prevailed at the time the last sale was made or those which represent the idea of a dealer regarding the price which he possibly may realize for one or more cars. Some other dealer may quote another newspaper on the basis on which he thinks wheat feeds may be bought, resulting at times in a wide difference between the prices as published by the two newspapers.

In heavy consuming and producing centers, and in cities where exchanges are located, the range between the prices quoted in the various local publications is usually narrow. In Western States and in Pacific Coast markets where exchanges are few the range between prices quoted is often large. Even in such markets as Portland, Oreg., and Seattle, Wash., which have exchanges where bids and offers for feedstuffs are made, wide variations in quotations appear at times. Actual transactions take place privately in these markets and the prices at which sales are consummated are usually not made public.

In most of the western markets similar conditions prevail. In the absence of exchanges, bids and offers are made by telephone and frequently meetings are held to reach an understanding on less-than-carload prices. The quotations appearing in newspapers in these markets are sometimes the actual prices obtained for one or more lots, but often they are estimates reached after a careful consideration of all circumstances by dealers. Many newspapers fail to show whether prices quoted are per bag, per ton, or per carload. Most of them, however, quote prices per bag as furnished by local retail feed dealers. Sometimes western dealers who handle stuff for local and neighboring country mills quote to newspapers a lower price than that prevailing, while dealers who trade in stuffs shipped in from the East often overstate the price, presumably to be able to

make a more favorable impression regarding conditions on prospective purchasers.

Other reasons for variations in prices are—

(1) Lack of agreement among dealers as to the volume of offerings.

(2) Purchases made at favorable figures by some dealers which are placed on the market at prices out of proportion with those quoted by dealers who must buy at prevailing prices.

(3) Unsold stuff in transit which is often disposed of by sacrifice on arrival.

(4) Forced purchases often made to fill contracts.

The lack of uniform grades for wheat feeds is another important obstacle to satisfactory price statements.

Still another difficulty lies in the confusion of meaning attached to a quotation. Is a quotation a record of a transaction, an offer, or a bid? The price furnished by a dealer may be one of these three. If it is one at which a trade was made, the question arises whether it was for cash, or for prompt, or for future shipment. It may have been a representative transaction, a sacrifice sale, or a forced purchase.

If the price quoted was an offer, it may have been for either prompt or future delivery. What is the duration of the offer? A dealer may state a price which he submits as an offer. If he is confronted by a customer he may modify his offer or he may withdraw it. Often a dealer submits a quotation when he wishes neither to sell nor to buy. The figure that he names is his idea of the value of the commodity in his market.

From producing or milling centers prices will be quoted at which a buyer can secure a carload of stuff. From consuming sections prices are quoted which are paid to the jobber or commission man or sometimes prices at which transactions between dealers are consummated.

WHAT TO ASCERTAIN ABOUT PRICES QUOTED.

The prudent buyer ascertains the following facts in connection with prices quoted before placing his order: (1) Grade; (2) quantity; (3) cash or credit; (4) bid or offer; (5) sight or arrival draft basis; (6) on spot or for shipment; (7) representative character and truthfulness of price; (8) branches of trade from which it originates.

At present the information concerning these factors is often incomplete, particularly in the Northwest and Southwest.

While some of the difficulties now encountered by dealers in ascertaining representative quotations can be removed only through educative effort, several of them could be overcome through a more complete market organization. It is doubtful, however, if all of them could be eliminated.

"Weather, Crops, and Markets," a weekly periodical issued by the United States Department of Agriculture, carries, each week, a table covering feed quotations in the principal markets, supplemented by a brief summary of market conditions of principal feedstuffs. The review and table are supplied to the public because of the usual difficulty in obtaining unbiased views, because of the need for re-

liable information, and because of the desirability of familiarizing consumers and dealers with actual conditions and prices in the principal markets.

Constant use of this information by buyers and sellers will result in a fairly comprehensive idea about conditions in general and in ability to interpret and use this information to advantage.

Much that upon first glance appears inconsistent, such as the wide difference in prices between various markets, soon becomes entirely clear if freight rates and existing conditions are taken into consideration.

It is not necessary to point out the advantage of a general knowledge of conditions, particularly when buyers have ample storage facilities and offerings are heavy, or when, in case of scant transit offerings, their supplies are sufficient to carry them over for a reasonable period.

FEEDSTUFFS LAWS.

The majority of the States have found it necessary to adopt laws regulating the sale and quality of feedstuffs. Unfortunately such laws differ materially in their requirements. The differences have led many mills to center their efforts on selling their feeds only in those territories where their feeds meet legal specifications. This lack of uniformity has seriously impaired a free distribution. In States where the legal fiber content requirement of wheat feeds has been placed rather low it is extremely difficult for spring-wheat mills to sell their offal. A number of States provide for sales of feeds by net weight. As mills often put up their feed in bags weighing 100 pounds gross, they are not allowed to make sales on the basis of 20 sacks of feed to the ton in these States. To overcome this difficulty a combined weight of feed and bags is invoiced at a certain price per ton.

In some States unadulterated wheat bran, middlings, or shorts are not taxed. Other States require neither registration nor license nor registration fee, while still others exact an inspection fee on wheat feeds whether pure or mixed with screenings.

The few illustrations given indicate that, particularly for a feed dealer or mill doing an extensive business, uniformity in regulations is very much to be desired.

The registration of feedstuffs, if sold delivered, is imposed upon the seller, who guarantees that the goods sold shall comply with the laws of the State into which they are sold. The registration fee and tax are also paid by the seller.

The collection of taxes or inspection fees necessary to carry out the laws regulating the sale and inspection of feedstuffs is performed in many ways. A few State laws provide for the payment of such taxes or fees at a nominal sum per ton, the seller to submit annually or semiannually a statement indicating the total feed tonnage sold by him in the State. Whether such States receive the full payment of the taxes due them is doubtful. It is, of course, extremely difficult to enforce collections in case the shippers are situated outside the State and refuse to make payment.

Other States charge a certain amount for the registration of each feed sold or exposed for sale, while still others require all feeds to

be marked with tags, obtainable from State officials having charge of the inspection work, at a certain amount for a given number, or provide for stamps to be attached to tags.

PRESENT NEEDS OF THE TRADE.

Many improvements are needed in the methods of marketing feedstuffs. Uniformity in the chief factors of marketing is probably the outstanding need.

UNIFORM STANDARDS FOR WHEAT FEEDS.

Although definitions for wheat feeds and ingredients thereof have been established, standards of quality have not been promulgated and are greatly needed. There are, for instance, thousands of millers in the United States whose ideas as to what should constitute bran and shorts and middlings seem highly variable. It is thought that if type samples could be agreed upon and could be placed in the hands of every miller and feed inspection department for guidance with respect to the observance of the feedstuffs laws, such arrangement would be of great benefit to the trade. Such a measure would enable buyers to determine the grade of feed they could expect to be applied on their contracts.

At present, unless the buyer stipulates in his contract the name of the mill whose product he desires, he does not know the quality of feed that will be delivered to him. He may buy by sample and in that case the feed he receives should be equal to the sample. To stipulate in a contract that the product of a particular mill is desired, while it affords some protection, does not always mean that the product of that mill will be received. Breakdowns, or inability to obtain wheat, may tempt that mill to purchase from competitors in order to fill its contracts, in which case usually its bags are furnished to the other mill in which to make shipment. This would lead the buyer to believe that what he receives is the product he contracted for. It should be stated, however, that in such cases every effort is made by the contracting mill to secure feeds of equal quality with those of its own manufacture, and that often buyers will receive a feed superior in quality to that which they expected to get.

A UNIFORM FEED LAW.

As a rule, State regulations pertaining to the sale of feedstuffs are intended merely to disclose to the purchaser the character of the feeds offered for sale, as feeds properly tagged or marked, although of inferior quality, may be legally sold when registered. State agricultural departments generally require that manufacturers and shippers doing business in their respective States file with the department a statement showing the ingredients contained in the feed intended to be sold and its guaranteed analysis. If a sale is made in the State, the manufacturer or shipper is bound to see that the feed shipped in complies with such regulations. These rules, however, do not always protect the feed consumer to the extent desired.

Because dealers, shippers, and manufacturers are liable to prosecution in the event an analysis of feed offered for sale is not in accordance with that guaranteed at the time of registration, the protein

and fat percentage of feedstuffs is often placed at a slightly lower and the fiber content at a little higher figure than their analyses would show in the majority of cases. This explains why often the analysis shown on the tags differs from that given at the time of registration. While there is no objection by State agricultural departments to the sale of feeds containing a better analysis than that specified in the registration blank, it is not permissible to sell feeds which show an analysis inferior to that indicated on the accompanying tags.

At present about one-sixth of the States have no laws regulating the sale or inspection of feedstuffs. This prevents consumers from securing adequate protection against quality and deficiency in weights.

The standards for wheat feeds adopted by the various States do not differ much. However, rules and regulations prescribing tagging requirements, the amount of registration fees, the manner of paying them, and other features vary widely and at times cause considerable confusion among distributors. This situation suggests the need for a uniform feed law.

The law should provide for uniform grades, weights, tagging, manner of marking and affixing tags, and manner of registration and inspection. Furthermore the law should provide for a more uniform method of procedure in cases where, because of difference of opinion between buyer and seller regarding quality, inspection is requested.

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THE SAIDY DATE OF EGYPT:

A VARIETY OF THE FIRST RANK ADAPTED TO COMMERCIAL CULTURE IN THE UNITED STATES.

By S. C. Mason, *Arboriculturist, Office of Crop Physiology and Breeding Investigations, Bureau of Plant Industry.*

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DISCOVERY OF THE COMMERCIAL VALUE OF THE SAIDY VARIETY OF DATE.

Of the hundreds of distinct varieties of the date palm recognized and propagated in the date-growing world scarcely a dozen have attained more than local importance and reputation, and of these only a few have attained commercial importance in Europe or America.

The discovery, then, of the commercial possibilities and adaptation to southern California conditions of the Saidy variety of Egvpt marks a new era in date production in the United States.

This new candidate for commercial favor in our American date-growing regions has been known to European explorers of the oases of the Libyan Desert (Fig. 1) for more than a century under the name "Sayd" or "Saydeh," while accounts of the excellence of the dates of these oasis dependencies of Egypt and of the caravans which brought them to the Nile Valley reach back to very remote periods. Modern geographers and surveyors of the Libyan Desert

of western Egypt agree in reporting the Saidy as the most abundant date variety in the five Libyan oases—Siwa, Baharia (*1*)[1], Farafra, Dakhla (*2*), and Kharga (*3*).[2]

In Gizeh Province of Egypt, within sight of the great Pyramids and on the very site of the ancient city of Memphis, are growing many thousands of trees of this variety under the name of "Sewi" (*22*), undoubtedly due to an early importation of offshoots from the Oasis of Siwa.

ESSENTIAL CHARACTERS OF A GREAT COMMERCIAL VARIETY.

The important commercial varieties of dates all agree in possessing certain characters essential to securing a market among European or American peoples. They are attractive in size and appearance, soft and luscious in texture, and of sufficiently high sugar content and pleasing flavor to appeal to the palate of the large class of customers who regard the date as a confection and as yet do not appreciate the qualities of the dry or bread dates which are most sought by the desert dwellers.

From the grower's viewpoint a great commercial date variety must be highly productive, and the fruit must have a sufficiently high sugar content to be self-preserving and to keep without fermentation during a long transportation by land or sea, plus a reasonable period of storage before marketing. Added to these qualities the successful commercial variety must be fairly prolific in the production of offshoots, by which alone its true type can be multiplied.

THE PRINCIPAL COMMERCIAL VARIETIES OF DATES.

Among the few varieties of dates with the requisite characters to assure them places in the commercial list the Deglet Noor takes the lead, its exquisite flavor and attractive appearance having long ago caused it to reach the top of the market in continental Europe and to be sold also for the fancy holiday trade in England.

Next to the Deglet Noor, the "Tafilet," or Medjhool, from the Tafilalet Valley of southeastern Morocco, since the occupation of Spain by the Arabs has held a high reputation in that country and almost as high in England. Sometimes this variety, in spite of its unattractive appearance and notwithstanding the fact that it is sold almost entirely in bulk instead of in attractive packages, brings high prices.

The third date of high market quality is, perhaps, the Fard, of the Semail Valley in the Sultanate of Maskat in southeastern Arabia. This is a small dark-colored date, but of attractive appearance, and the flavor is evidently appreciated by the American consumers, since it brings the highest price of all the varieties brought to this country from the Persian Gulf region.

The fourth of the great commercial dates of the world is doubtless the Halawi, from the lower Euphrates Valley in Mesopotamia. This variety has the highest output of all commercial dates grown and is sold in enormous quantities in the English and especially in the Amer-

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[1] Serial numbers (italic) in parentheses refer to "Literature cited" at the end of this bulletin.

[2] The spelling of these oasis names, except where quoted, follows that used by the surveys department of the Public Works Ministry of Egypt.

ican markets.[3] The imports to America of this variety reach as high as twenty to thirty million pounds a year, and the dates sell at wholesale prices ranging from 5 to 7 cents a pound in normal times. At this price it is the cheapest dried fruit suitable for consumption without cooking or other preparation that reaches the American market in large quantities. It does not compare in quality with any of the other dates named, but it does compete with them advantageously in price.

CHARACTER AND EARLY HISTORY OF THE LIBYAN OASES, THE HOME OF THE SAIDY DATE.

These oases are irregular depressions in the great Libyan Plain, largely the result of wind erosion. Their only source of water at present is numerous artesian wells, though doubtless natural springs were found in prehistoric times. Many of these wells were bored during the Roman occupation, about the beginning of the Christian era. According to Beadnell (*2*), the Dakhla Oasis has about 420 ancient Roman wells still in active operation, though supplemented now by many modern ones. The source of this artesian supply is believed to be the rain belt of the African interior.

According to the same authority, the Dakhla Oasis had a total of nearly 200,000 date-palm trees in 1901, or about 7½ trees for each inhabitant. The greater number of these palms are of the Saidy variety. The dates from these oases for many years have been brought over to the Nile Valley by the Bedouin traders, who sell them under the name "Wahi," which in Arabic means the date from "el wâh," or the oasis.

EARLY EGYPTIAN KNOWLEDGE OF THE DATE PALM.

The history of the oases has been interwoven with that of Egypt from a most remote period. Evidence has been found not only of the predynastic occupation of Kharga, but it has been conclusively shown by Beadnell that this reached back into a stone age. We can not conceive of a population in these oases, distant a journey of only a few days from the Nile or from the Mediterranean coast, not being in more or less close touch with the Nile countries and governments. Apparently from a very early period the Egyptian governments sought to rule these oasis dwellers and to collect tribute from them. Sometimes under nominal subjection, they were by no means loyal, and repeated rebellions had to be put down.

The oases were made places of banishment for political offenders, even of royal blood, and following the Christian era many noted men of the Coptic Church were banished to both Kharga and Siwa, so that a Coptic community of many thousands existed at Kharga, and the ruins of the Christian necropolis vie in interest with the temples of the Egyptian deities. Kharga was from a very remote time an

[3] In the lowest commercial rank may be placed such dates as the Khadrawi and Sayer, also from the Mesopotamian region, which are not bought willingly by the importers of dates into America, but are merely included in bulk purchases of the entire output of an orchard. Considerable quantities of these varieties reach America and England, where they are sold at prices from 10 to 25 per cent below those paid for Halawi dates. Small quantities of the Amri date, a large but poorly flavored variety from Egypt, are shipped to Europe, but this date can not be said to play any important part in the markets of the world.

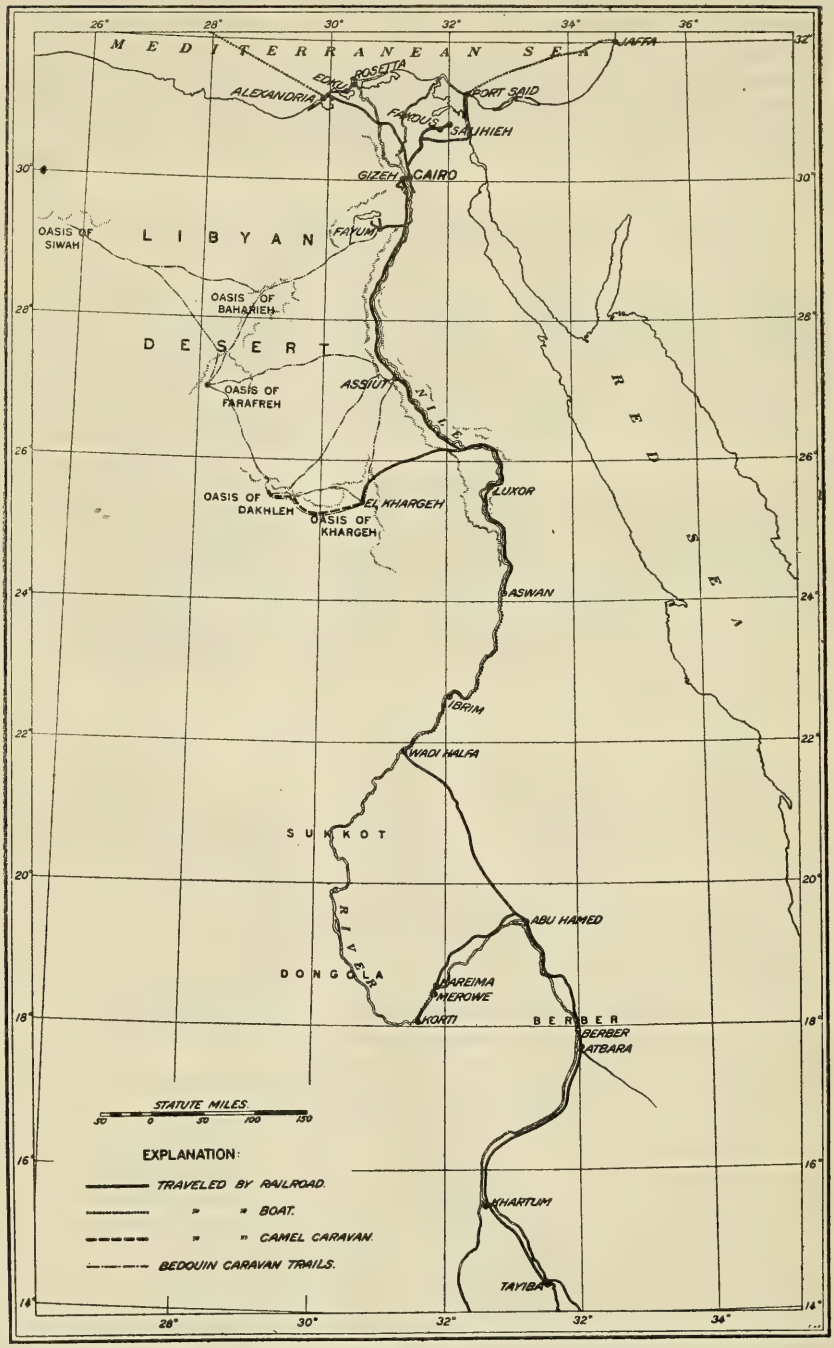

Fig. 1.—Map of Egypt and the Sudan, showing the route of travel and the localities where dates were studied.

important station on the great caravan route between the upper Nile countries and Egypt, just as Siwa was on the great caravan route to west Africa when Herodotus wrote of the stations from Thebes to the Pillars of Hercules.

Fischer (*13*) calls attention to the writings of Dümichen (*11*) and Brugsch (*8*) on ancient Egyptian inscriptions bearing on the Libyan oases.

Brugsch (*8*), who made a close comparison of the early Egyptian references to the western oases, contends that the Arabic word for oasis, *wâh*, is from the Coptic *wah* or *uah*, and that this again is derived from an early Egyptian word for an envelope or the wrapping of a mummy, *ouit* or *uax*.

Breasted records that Puemre, architect under Queen Hatshepsut and later under Thutmos III (1501 to 1447 B. C.), is represented as receiving "tribute from southern and northern oases," while the scribes record the amount (*5*, v. 2, pp. 385–386); and Intef in his stila, where he describes himself as the "Royal Herald of Thutmos III," also proclaims himself as "chief of all the oasis country" (p. 763). But the oasis dwellers have been hard to hold in subjection, and Mereneptah, successor to Rameses II (1225 to 1215 B. C.), was confronted with a combined invasion by the Libyan forces and the coast peoples, which the inscriptions show he was able to overthrow with a great slaughter and the capture of many prisoners (p. 569).

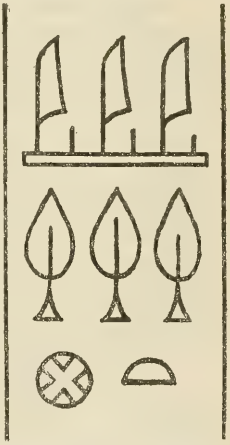

Fig. 2.—Ancient name of Siwa Oasis, "Sokhit am or ami," signifying "orchard of palms."

Dümichen (*11*), after a most painstaking study of the early inscriptions, tells us that the ancient name of Siwa Oasis was "Sokhit am or ami," signifying an "orchard of palms" (Fig. 2), and that the Egyptian name for the dwellers of Siwa was literally "men of the palm orchards (Palmenhainmänner). He gives us most graphically this further conclusion (p. 33):

> Already in ancient times there were established caravan routes between the oases and the upper, middle, and lower sections of Egypt, over which there came in great quantity the valuable products of the oases; especially wine from Chargeh and Dachel, dates from Siwa, and natron from the Wadi el Natron; also olives and lemons, medicinal herbs, dyestuffs, and many other articles.

The earliest of these inscriptions he places at the time of "Thutmosis III, the sixteenth century B. C. (16 Jahrh. v. Chr.)." (It will be noted that Breasted places this reign considerably later.) This is most interestingly confirmed by Ball and Beadnell (*1*) in their account of the Egyptian antiquities of Baharia Oasis. They refer to the discovery by Ascherson in 1876 of a stila of the time of "Thotmes II," showing that at that early period (between 1501 and 1447 B. C., according to Breasted) this oasis was an Egyptian dependency and the worship of Egyptian deities was established there.

A most characteristic record of this oasis region of artesian wells was a suit for the possession of a "flowing spring" and "cistern" brought by Nesubast, before Waycheset, the new governor, "lord of the oasis" (of Kharga and Dakhla) and "chief of irrigation," appointed by Sheshunk I, of the Twenty-second Dynasty (945 to 924

B. C.). After a delay of 14 years this claimant won his suit and had his title established (*5*, v. 3, pp. 726–727).

ACCOUNTS OF OASIS DATES BY MODERN TRAVELERS.

The first modern European traveler to visit Kharga Oasis seems to have been Poncet (*23*), who wrote of his journey from Syout (modern Assiut, or Siut), in October, 1698, in his "Voyage to Ethiopia," as follows:

> Having at my Return found all the Company met, we set forward on the 2d of October early in the Morning, and from that very day we entered a frightful Desert. . . . We arrived on the 6th of October at Helaoue: 'Tis a pretty large borough and the last that is under the Grand Signior's Jurisdiction. . . . Helaoue is very pleasant and answers fully its Name, which Signifies a Country of Sweetness. Here are to be seen a great Number of Gardens watered with Brooks, and a World of Date-Trees which preserve a continual Verdure.

Paul Lucas, a French traveler who was commanded by Louis XV to write the account of his voyages, about 1700, gives the earliest modern account of the date industry of the Oasis of Baharia, from which the United States Department of Agriculture obtained its first importation of Saidy offshoots under their true name. He is cited by Rennell (*24*) (Geog. of Herodotus, v. 2, pp. 204–205), as follows:

> There is in the desert, at the distance of *some* journeys[4] from Faiume (the city so named), a place of inconsiderable extent full of palm trees which bear the *best dates* in all *Egypt*. [The same is said by Jacutus, respecting the superior quality of the fruits of the oases.] The Arabs, who possess and cultivate this spot, draw their scanty supplies of water from the wells, which they have, with much labour and industry, dug in the desert, and water them with great care. They pay their tribute to the Pacha in dates. (Vol. ii, of the Third Voyage of Lucas, p. 206.)

Rennell says:

> A position of some journeys' distance from the Faiume, and in the desert to the west, can answer to no other place than the Lesser Oasis, which by our *data* falls at about five journeys from the town of Faiume; four from the nearest part of the lake of the same name.

As the "Lesser Oasis," or "Oasis Parva," was the earlier designation of what is now known as Baharia, where in January, 1820, Cailliaud (*9*) noted that "the best dates of the region are called Saydeh;" no great stretch of the imagination is needed to suppose that in the time of Lucas, about 1700, there were gardens of Saidy trees which bore "the best dates in all Egypt," from which the tribute to the pasha was paid, for we may be sure that potentate accepted as tribute none but the best.

William G. Browne (*7*) was the first modern traveler to reach the Oasis of Siwa or Jupiter Ammon. In his account of this journey he says:

> The information I had obtained in Alexandria having induced me to resolve on attempting to explore the vestiges of the Temple of Jupiter Ammon from that place, I procured a proper person as interpreter and made the necessary arrangements with some Arabs, who are employed in transporting through the desert dates and other articles between Siwa (a small town to the westward) and Alexandria, to convey my baggage and provisions and to procure for me a secure passage among the other tribes of Arabs, who feed their flocks at this season in the vicinity of the coast. * * * When the Arabs had finished the

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[4] Ancient writers frequently refer to the distance traveled in a day by caravan as a "journey."

business on which they came to the city, and had fixed on an hour, as they thought, auspicious to travelers, they made ready for departure and on Friday, 24th February, 1792, we left Alexandria.

They took the route by the seacoast, "the same that Alexander had chosen for the march of his army." On Sunday, the 4th, after 75½ hours of actual travel along the Mediterranean coast, they watered the camels at a well affording a copious supply of sweet water, then struck inland, toward the southwest.

On Wednesday, the 7th, at night, we had reached a small village called Karet-am-el Sogheir * * * This village is independent, and its environs afford nothing but dates, in which even the camels and asses of this quarter are accustomed to find their nourishment * * * For about a mile and a half from Karet-am-el Sogheir the country is sprinkled with dates, and some water is found.

They arrived at Siwa on Friday, the 9th, late at night, after 62¼ hours of actual travel from the coast.

We at length came to Siwa, which answers the description given of the oases, as being a small fertile spot, surrounded on all sides by desert land. It was about half an hour from the time of our entrance on this territory, by a path surrounded with date trees, that we came to the town, which gives name to the district.

This first Christian visitor to their oasis for many centuries was not made at all welcome by these Mohammedans;[5] in fact, he was at times in no small danger. He was naturally more interested in the ruins of the ancient temple than in their agriculture, but he takes time to tell us:

The oasis which contains the town Siwa, is about 6 miles long and 4½ or 5 wide. A large proportion of the space is filled with date trees; but there are also pomegranates, figs and olives, apricots and plantains; and the gardens are remarkably flourishing. * * * Their list of household furniture is very short, some earthenware made by themselves, and a few mats form the chief part of it, none but the richer order being possessed of copper utensils. They occasionally purchase a few slaves from the Marzouk caravan. The remainder of their wants is supplied from Kahira or Alexandria, whither their dates are transported, both in a dry state and beaten into a mass, which when good in some degree resembles a sweetmeat. * * * They drink in great quantities of the liquor extracted from the date tree, which they term *date-tree water*, though it has often, in the state they drink it, the power of inebriating.

Frederick Horneman (*18*) was the next after Browne to reach the Oasis of Siwa and explore the ancient temple of Jupiter Ammon. His account of the journey from Cairo to Aujila adds something to the fund of information accumulated from other travelers. He joined a company of merchants of Aujila, who had their rendezvous at "Kardassi" or "Kardaseh," still a well-known village a few miles north of the Gizeh Pyramids, from the vicinity of which the writer purchased date offshoots in the springs of 1920 and 1922.

The party set out from this village on September 5, 1798, joining "the great body of the caravan, which yearly returns from Mecca." The caravan went by the way of Wadi el Natrun, and on the eleventh day, September 15, the traveler says, "we came to an inhabited spot, after 5 hours' march arriving at the small village of *Ummesogeir*." This is the junction point with the trail from Alexandria along the coast, over which Browne had arrived March 7, 1792, recording the village as "Karet-am-el Sogheir."

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[5] Recent travelers there report very hospitable treatment, which accords with the writer's experience in Kharga and Dakhla.

Horneman says.

The people of Ummesogeir are, indeed, in every respect poor, depending wholly for subsistence on their dates, which they in part sell to the Arabs of the desert and in part carry to Alexandria and exchange for corn, oil, or fat.

Of Siwa, after a general description of the town and people, he tells us:

Its soil is a sandy loam, in some places rather poached or fenny; but, assisted by no great industry of the natives, it produces corn, oil, and vegetables for the use of man or beasts. Its chief produce, however, consists in dates, which, from their great quantity and excellence of flavor, render the place proverbial for fertility among the surrounding Arabs of the desert. Each inhabitant possesses one or more gardens, making his relative wealth, and these it is his whole business to water and cultivate. * * * The dates produced are preserved in public magazines, of which the key is kept by the sheik; to these storehouses the dates are brought in baskets closely rammed down, and a register of each deposit is kept.

Horneman refers to the fact that dates are used as a method of exchange and in the place of money in payment of tributes, fines, etc.

Justice is administered according to ancient usage and general notions of equity. Fines, to be paid in dates, constitute the punishments; for instance, the man who strikes another pays from 10 to 50 *kaftas*, or baskets, of dates; these baskets, by which everything in this place is estimated and appraised, are about 3 feet high and 4 or 5 feet in circumference. * * * I was told much of the riches of this people and should suppose there must be men of considerable property amongst them, as they have a very extensive traffic in dates with different and remote countries, pay no tribute, and have little opportunity of dissipating the money they receive.

Horneman was of the opinion that the language of Siwa was "not fundamentally Arabic," but "a dialect of that in use throughout the great nation of Africa * * * and which may be considered as the aboriginal."

He records that the Siwa word for dates is "tena."

Sir Archibald Edmonstone, Bart. (*12*) is regarded as the modern discoverer of the "Inner Oasis, or Dakhla."

The party of Edmonstone left the neighborhood of Beni Adi, on the Nile, on February 11, 1819, and after a journey of six days reached the village of "Bellata" (Belat, of modern maps), in the eastern section of Dakhla. He explored the oasis as far as "El Cazar" (El Kasr) in the northern part of the western section. (See map of "The Oases of the Libyan Desert," by Hoskins (*19*).

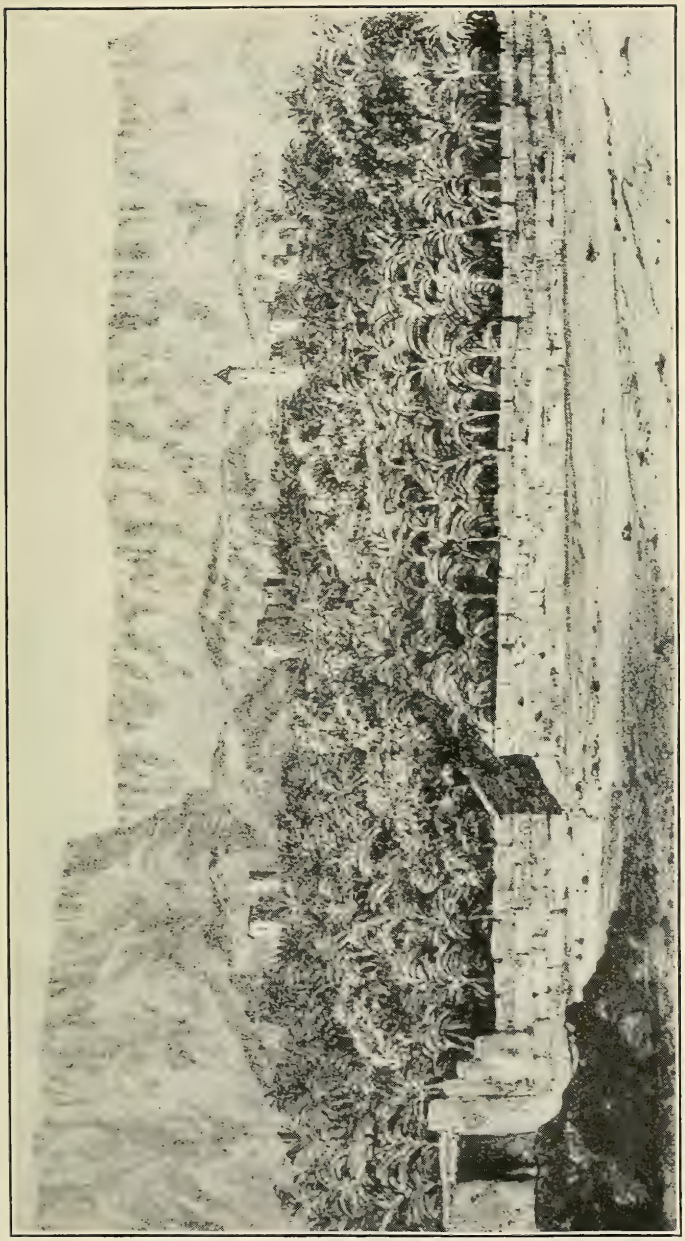
Edmonstone makes frequent references to the date groves, and one plate (Pl. I, photographed from Edmonstone's "View of El Cazar") gives a most realistic picture of the date gardens surrounding the famous "El Cazar" and the escarpment of the Cretaceous cliffs to the northward. He writes of El Kasr as follows:

The situation of this place is perfectly lovely; it is seated on an eminence at the foot of the line of rock which rises abruptly behind it and is encircled by extensive gardens filled with palm, acasia, citron, and various other kinds of trees, some of which I have rarely seen before in these regions.

Edmonstone quotes freely from other explorers, in part as follows:

The fertility of the oasis has been deservedly celebrated. Strabo asserts the superiority of the wine; Abulfeda and Edrissi mention the luxuriance of the palm trees; and Vansleb[6] says, "The best dried dates are brought from Elwah, which region lies 3 days' journey inland from Siout. These are so fleshy and sweet that others would be considered sour and bitter after them."

[6] Vansleb was a Dominican who traveled in Egypt and Nubia in the years 1672–73.



VIEW OF EL CAZAR (EL KASR), DAKHLA OASIS, EGYPT.

From "A Journey to Two of the Oases of Upper Egypt," by Sir Archibald Edmonstone, Bart., London, 1822.

FIG. 1.—SAIDY DATE GARDEN NEAR HAWAMDIA, IN UPPER GIZEH PROVINCE, EGYPT.

Photographed by the author in May, 1920.

FIG. 2.—A SAIDY DATE PALM, 40 YEARS OLD, STILL SHOWING NUMEROUS OFFSHOOTS, NEAR HAWAMDIA, IN UPPER GIZEH PROVINCE, EGYPT.

Photographed by the author in May, 1920.

On page 54 Edmonstone adds: "Dates are an article of commerce with Egypt, and we often met caravans conveying them."

No mention has so far been made of the varieties of dates which were then grown in the oases, and our earliest authority on this is Frédéric Cailliaud (*9*), a young French engineer, who visited the Oasis of "Syouah," going in from Fayum in December, 1819. He thus explains his selection of the route via Fayum:

As I found it impossible to enter Syouah by way of Terraneh, I decided to go by Fayum, joining one of the caravans which go to this oasis for the trade in dates, which they market at Cairo and Alexandria.

From this paragraph we get an important side light on the magnitude of the trade in dates from Siwa Oasis a century ago. Describing the products of this oasis, he says:

The principal trees of the oasis are the date palms, the olives, the apricots, and the pomegranates; more rarely are the fig, the plum, and the apple trees, while the doum palms, trees common in the southern oases, do not occur here. Five varieties of dates are distinguished, one of which has no seed; they are called *gazaly, freyeh, sâyd, el-ka'yby,* and *ouaedy;* the first also called *soultany,* are most highly esteemed. Generally the dates of the oasis are superior to those which are produced on the borders of the Nile. The *ouaedy* dates are used for food for camels, donkeys, and other animals. The *sâyd* dates are packed fresh in baskets for exportation. The oasis abounds in dates; this fruit is used extensively in commerce.

Cailliaud took the long caravan trail from Siwa to "El-Ouâh el-Bahryeh." where he arrived January 1, 1820. He thus vividly describes their approach to the oasis as heralded by spots of vegetation and tamarix bushes and finally the appearance of the palm groves:

On the 1st of January, 1820, we set out at half past 9 in the morning following the Ayn-Beledy Valley in the east. The grass, asclepias, tamarix, and the small marshes that we found along our route revealed to us that we were near an oasis. Soon we could see the date palm. With what pleasure we observed this rich verdure in the midst of the sands of the desert, after having endured so much of fatigue, anxiety, and privations! * * *

At midday we arrived at El Quasr, the largest village in the oasis, which the Arabs call El-Ouâh el-Bahryeh, being the most northern oasis on the Egyptian frontier.

Cailliaud spent the greater part of January in studying the antiquities of this oasis and the customs of the people and noted the arrival of a caravan of traders from the Nile:

On the 10th of the month a small caravan came from Minyeh, a town in lower Egypt, loaded its camels with dates, and left after a few days.

Later (p. 177), Cailliaud tells us definitely what these export dates are:

Dates form the principal product of this oasis; although good they are less esteemed than those of the Syouah which surpass all others. The best ones of the region are called *Saydeh;* they are packed, still fresh, in baskets and are exported in this state.

Twelve years later, in October, 1832, Hoskins (*19*) gives this graphic account of the date trees of Kharga and their date commerce with Egypt:

El Khargeh, 20th October.—We rode here in three hours and a half. I shall include in this description of the metropolis of the oasis the information I obtained both now and on a subsequent visit after leaving the antiquities. The view of El Khargeh at a distance is very prepossessing. Its greatest attraction consists in a magnificent thick forest of date trees, which extends probably a mile toward the north and south and is surrounded by a brick inclosure, like

the wall of a park. One or two houses are built in this inclosure, forming, as it were, the gates of the city. The flat roofs of many habitations are visible among the trees; and the domes of two mosques, with their galleries, from which they cry the hour of prayer, are conspicuous, towering even above the lofty palms.

Later (p. 85), this author says:

Many of the sheakhs and merchants are rich and independent. * * * They send their dates to the Nile, where, from their just celebrity, they obtain the highest prices given for that description of fruit; and they bring back in return wheat, of which there is a deficiency in the oasis, sundry articles of wearing apparel, arms, ornaments, spices, coffee, mirrors, glass beads, and other little articles of hardware, and which they sell again at an immense profit. The oasis produces rice, but very inferior to that of the Delta, wheat, millet, dourah (the latter in abundance), and the various fruits which I have mentioned in describing the gardens. Their great source of wealth, however, and all their commerce and prosperity, depend upon their extensive forests of date trees.

Heeren (*16*), in his book published in 1832, has this to say regarding Siwa of his time:

[Page 206:] On the south of the temple, at the distance of a full quarter of an hour's walk, arises, in a delightful grove of dates, the fountain of the sun, formerly sacred to Ammon. It forms a small pool about 30 paces in length and 20 wide. It is said to be 6 fathoms deep, but is so clear that the bottom is seen, from which bubbles continually arise like those of a boiling caldron. The temperature of the water varies; it is warmer at night than in the day, and about daybreak is wont to smoke. It is probably a hot spring, the warmth of which is not observed during the heat of the day. A small brook, which runs from the pool, unites itself soon after to another spring (Herodotus says that there are other wells of fresh water) which likewise arises in the palm grove and runs toward the ruin, near which it forms a swamp, probably because its ancient outlets are stopped up.

The early and high cultivation of the oasis is still shown by its rich produce of dates, pomegranates, and other fruits.

The date is the most cultivated and is obtained in vast quantities and of very fine flavor. In favorable seasons, say the inhabitants, the whole place is covered with this fruit; and the yearly produce amounts to from five to nine thousand camel loads of 300 pounds each. The annual tribute is now also paid in dates. * * *

Following this ancient caravan road to the westward, he narrates:

[Page 213:] Leaving then the lofty palms and the sacred groves of Jupiter Ammon, the last traces of vegetation and animated nature soon disappear.

The southern desert of Barca opens its arid plains, only interrupted by parched barren hills. For 10 days this continues, till at length the date groves of Augila appear, and the wearied caravan again lands on one of those fertile islands which nature has sprinkled with so sparing hand over the sandy ocean of Africa.

Augila is a well-known name both in ancient and modern geography. It is at present the capital of a district which comprises two other villages. Horneman reached it from Siwah after nine long days' journey, which, if we reckon them as ten common ones, confirms what Herodotus states as to the distance between the two stations. Augila owes nothing to its size, nor is there anything remarkable about it; but it is principally known as being the great thoroughfare for caravans, which still touch at it in their route from western Africa to Cairo. Even in the present day a portion of the inhabitants devote themselves to the caravan trade. Besides this, Augila is a principal mart for dates, which have always been found there of an excellent quality and in great abundance. Herodotus expressly remarks that the Nasamones in the Regio-Syrtica annually made a journey to this place in order to purchase a supply of this fruit. (Herodotus (*17*), iv, 182.)

[Page 215:] Augila produces nearly double the quantity of dates that Siwah does. In this manner is the testimony of Herodotus again confirmed.

We thus have, from more than a century ago, circumstantial accounts of an extensive commerce in dates between these four chief

oases of the Libyan Desert and the Nile Valley. And Herodotus bridges the historical gap between the ancient Egyptian and the modern accounts. We have the "Sayd" or "Saydeh" specifically mentioned by Cailliaud (*9*) as the export date of "Syouah" and "Bahryeh," though the "Sultani" is referred to as the choicer variety. This is explained by the well-known preference by the desert dwellers for a dry date rather than a soft date. Beadnell in 1898 and the writer in 1913 found the Saidy to be the great export date both of Kharga and Dakhla. Sheik Abu Bakr of Dakhla then positively stated: "We have this same date in all five of the western oases" (including Farafra).

Considering the great age attained by date palms and the slow change in oriental customs and institutions, there can be little doubt that while the variety was not specifically named for Dakhla and Kharga, the Saidy was the export date of those oases in Cailliaud's time as it is to-day.

How much farther back its history extends can only be conjectured, but a great date industry takes years to establish in any country. Considering that in these oases a century ago was a culture so extensive and well established that caravans from the Nile cities in quest of these dates were of frequent occurrence over well-established trails, a commerce old in the time of the Pharaohs, the origin of the Saidy variety vanishes in the dim past of that marvelous land.

With so extensive and long established a date industry, based on the excellence as well as the packing and keeping qualities of the Saidy variety, it is remarkable that later writers on the dates of Egypt have given it such scant recognition.

Delchevalerie (*10*), "Chief Gardener of His Highness the Khedive," in a rather exhaustive pamphlet, "The National Tree of the Egyptians, the Date Tree," published in 1873, describes by name 30 varieties of dates but makes no mention under those names of the Saidy or "Wahi." His No. 18, however, is "Dattes de l'Oasis Syouy" or, in the Arabic transliteration, "Balah Syouy," of which he says: "Fruits fragrant, very sugary, and of good quality. This variety grows in the Oasis of Syoua, or Jupiter Ammon, in the great Libyan Desert." It must be noted that as in the case of this writer's No. 10 "Balah Yemany," and No. 29 "Balah Sukhouty," this is purely a locality name, not a descriptive, variety name, as his No. 28 "Soubah el Arous," "the bride's fingers." The description was evidently taken from dates imported from "Syoua" Oasis, where no variety under the name of "Syouy" has been listed by any traveler, but agrees well with that of the Saidy, their great export date for a century past. This listing of "Balah Syouy" from the "Syoua" Oasis seems to throw light on the origin of the variety now so extensively grown in Gizeh Province and known there as "Sewi," to which reference will be made later.

Rohlfs (*25*), whose expedition explored the Libyan oases in 1873–4, states, on the authority of Stephan (*26*), p. 32), that the annual exportation of dates from "Siuah" Oasis was 30,000 centners, or 3,000,000[7] pounds, and that during the export season from October

[7] The estimate of Heeren (*16*) was a maximum of 2,700,000 pounds. If Mr. Brown (*6*) is correct in placing the present output of dates from Sewa at "between 740 and 770 tons per year" the export from this oasis would seem to have declined by one-half since Rohlfs' survey.

to the 1st of March caravans of 100 camels were arriving and departing daily, bringing in grain and all sorts of merchandise and loading back with dates. He gives a most realistic account of the great date warehouse, or "Dattelager," shown him by the governor of the city of "Siuah," having mud-brick walls in part surrounded by moats or trenches, but without roof. Here each citizen might store his dates, awaiting transportation or his supply for consumption during the year. He notes that the stores included fruits of the finest sorts, the Sultani and Rhazelli, as well as the common sorts used as food for their domestic animals. But already the usual yearly exportation of about 30,000 centners or hundredweight had been made to the valley, which no doubt comprised largely the Saidy variety.

The practice of storing dates in such warehouses had been noted, it will be recalled, by Horneman in 1798.

The earliest English notice of the Saidy variety is an article on Siwa Oasis in the Geographic Journal, London, by Wilfred Jennings-Bramly (*20*). On page 602 he says:

> They cultivate five kinds of dates. The best, the Ghrasali, is too juicy to be exported; the Faraghi, which will keep from three to four months, is exported to Alexandria. The Saiedii is the common Arab food, of which every Bedouin keeps a store, as it will keep good for a year. Out of it is made the paste called ar-gool, or moona (mortar). The dates are trampled upon until they adhere together into a paste, the sugar in the fruit crystallizing and helping to preserve them. The Sultani, of which Siwa possesses but a few trees . . . is chiefly grown in the small oases. The Gargha [is] the least valued of all and therefore kept for home consumption and camel food. All these dates are dried on the sand of the date yards and carry away with them a good deal of the soil, but to the Arabs this does not seem to detract from their excellence. They are packed for sale in long, flat baskets made of the palm branches called saa, which is a recognized measure for dates, so that you buy half or quarter of a saa. Two saa, one slung on each side, are a camel load.

This writer makes use of a very different transliteration for the varietal names from that used by Cailliaud (*9*), but we can recognize most of the varieties. He missed the commerce in the "Saiedii," which gives it its greatest importance, but brings out its remarkable keeping quality and the characteristic of the graining or sugaring of the flesh after it has been packed for a time.

Ball and Beadnell (*1*), in their account of the agricultural conditions in Baharia Oasis, from a survey begun in 1897, state:

> Dates palms are taxed 15 millièmes per annum [equivalent to 7½ cents]. The number of trees at the 1897 assessment was 93,000, or about 15 per inhabitant. The great article of produce in the oasis is therefore dates, and at the date-gathering season the inhabitants are busily employed in gathering, drying, and packing the fruit for export to the Nile Valley. Three-fourths of the whole date production are exported. The dates are of excellent quality and find a ready sale, the villages of the oasis being crowded with camels and traders from the valley each November. A camel load of dates,[8] packed in two plaited-grass bags, is bought in the oasis for 500 millièmes and is said to be sold in the Nile Valley for four times that sum, so that the Bedouins, to whom the trading is almost wholly confined, even allowing for the difficulties of transport, make a good profit.

Doctor Ball, the chief of this survey, told the writer in September, 1913, that by far the greater number of date trees in Baharia Oasis were of the Saidy variety.

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[8] About 320 pounds; at pre-war prices bought for half a pound Egyptian, or about $2.50 United States money, and sold in the Nile Valley for £E2, or a fraction over 3 cents per pound.

QUEST FOR THE "WAHI" DATE BY THE UNITED STATES DEPARTMENT OF ARICULTURE, PROVING THE IDENTITY OF THE "WAHI," "SEWI," AND SAIDY DATES.

This brings the fragmentary but very vivid and consistent story of the oasis date industry down to the time when the Saidy variety came to the notice of the staff of the Bureau of Plant Industry.

In 1901 David Fairchild, Agricultural Explorer of the Department of Agriculture, saw a date called "Wahi" in the bazaars of Fayum and recognized its excellence in spite of the unattractive packing. From samples sent by Mr. Fairchild to the Department of Agriculture at Washington, D. C., Walter T. Swingle (*27*) wrote the following paragraph, appearing in Bulletin 53 of the Bureau of Plant Industry, issued April 28, 1904:

Another sort of great promise is the Wahi, of which samples were secured by Mr. Fairchild in the market of Fayoum, in west-central Egypt. This variety is said to come from the oasis of Seewah, known to the ancients as Ammon, or Ammonium, some 300 miles to the westward, in the interior of the Sahara Desert. The date is brown, less transparent than the Deglet Noor, but rather longer and decidedly broader; the seed is blunter and much more irregular in outline. The flesh is yellowish, granular midway between the skin and the seed, and of a most delicious flavor. This date had been gathered and kept, with no precautions against drying out, for at least eight months when it was received at Washington, but it was still in very good condition, except for the attacks of weevils. It seems to be a better keeper and to have a higher flavor than the Deglet Noor. Nothing is known as to the palm which produces this date, but from the quality of the fruit it is presumably a late-maturing variety.

Mr. Fairchild's notes on the "Wahi" date were published in Bureau of Plant Industry Inventory No. 10 of seed and plant introductions (issued February 8, 1905), where it is described as follows:

7001. PHOENIX DACTYLIFERA. Date.

From Fayum, Egypt. Received through D. G. Fairchild (No. 617), July 1, 1901.

Wahi. Twenty kilos of dried fruit of a variety of date which is said to have been brought from Siwah, a small village in the oasis of Bahriyeh. It is to my taste the sweetest drying date in Egypt—at least it is much sweeter than the Amri or any other I have tasted. It has a very peculiar mealy flesh of golden to greenish yellow. The skin is very thin and smooth and of a golden brown shade. Seed short, rather large, and clinging to the meat rather firmly. The flesh is somewhat granulated with the sugar. I can not be certain that this variety did really come from Siwah, but it certainly is a sort not commonly seen at this season in Cairo and is superior in flavor to that which is considered the best in Egypt. The word *Wahi* signifies merely oasis, according to Mr. H. A. Rankin, of Fayum.

From this account it seems that Mr. Fairchild had a clue as to the origin of the "Wahi" date which should have led to the early discovery of its identity with the Saidy. On April 2, 1904, Mr. Swingle wrote to Mr. Fairchild in part as follows:

I was mistaken in stating that the *Sultani* date is reported for Baharieh, the Petit Oasis; it is the *Saydeh* date which is named by Cailliaud as the best date in the oasis, though he expressly says "not so good as Siwah dates, which are best of all." Of the *Saydeh* he says, "On les entasse, encore fraiches, dans les panniers et on les exports dans cet etat."

There is a *Sayd* date in Siwah also packed in baskets when fresh for export. Probably the *Saydeh* of Baharieh and the Sayd of *Siwah* are identical.

It would be well to ask for offshoots of the *Saydeh* date *if it is different* from the Wahi. [The last italics are the writer's.]

As a matter of fact, Mr. Rankin was closely questioned by Mr. Fairchild on this point, as is shown by the following extract from his letter of April 15, 1904:

W. T. Swingle, who has been making a special study of the date palm, sends me the following notes regarding the dates reported from the oases east of Fayum (copy of notes not attached).

They would seem to indicate that the date under the name of "Saydeh" is the best date which occurs in the Oasis Baharieh, and it is important to determine whether the Wahi date, which is said to come from Siwah, really occurs in the Oasis of Baharieh or if the "Saydeh" is not the sort which really comes to the Fayum and is called by the Arabs "Wahi." Should arrangements be made for you to make the trip to these different oases, we would want suckers of this "Saydeh" date.

An article on the date palm by Fletcher (*14*) in the Agricultural Ledger, Calcutta, 1906, concludes with a table of "well-known varieties of dates" in which appears among others the "Wahi, or Sewi," from the "Seewah Oasis" of Egypt:

Class.	Country.	Center.	Name of variety.	Date of ripening.	Soil requirements.	Market.	Character of fruit.
1. Soft....	Egypt...	Seewah Oasis.	Wahi, or Sewi...	August..	Sandy...	Fayum, Egypt.	Plump and yellow.

Fletcher had before him Bureau of Plant Industry Bulletin 53 and credits Swingle (*27*) with giving considerable material. The source of this combination "Wahi, or Sewi," is difficult to guess. None of the writers who had visited the oasis had noted any variety called "Sewi." Only Delchevalerie (*10*), who was not an explorer, had mentioned "Balah Syouy" from "oasis de Syoua."

We find Foaden and Fletcher (*15*) listing 10 leading varieties of Egyptian dates, and the "Sewi" is again credited to "Sewa Oasis," as follows:

(4) *Sewi*, which as its name indicates, is largely cultivated in the Siwa Oasis, is a comparatively short but thick and yellow date. The ripe fruit is usually pounded and kneaded together into a kind of paste or cake known as "Agoua." The finest sorts are preserved in small skin bags, the stones being first removed, while the common sorts are kept in bags made of date leaves. It is thus largely used as food during the whole year and constitutes one of the chief articles of food among the poorer classes.

The foregoing rather indefinite description might apply equally well to dates from the oases (the Saidy) or to that found in upper Gizeh which has till now been known as the "Sewi." That the "Sewi" of Gizeh Province, orchards of which were actually in sight of the School of Agriculture at Gizeh, of which this author was principal, should have been completely overlooked seems rather astonishing, although in justice to Mr. Fletcher we must add that "Chapter XIII, Fruits," is credited to G. Bonaparte (*4*).

Beadnell (*3*), formerly of the Geological Survey of Egypt, gives the following account of the "Saidi" date:

In Egypt there are about 50 varieties of date palm, the chief kinds in Kharga Oasis being the Saidi, Tamar, Falig, and Hamrawi. The Saidi dates of the oasis are generally considered to be superior in flavor to almost any other Egyptian variety and have in consequence a ready sale in the Nile Valley. The other varieties are not exported to any great extent, except, perhaps, the Falig;

the Tamar, while producing a heavier crop than the other kinds, yields fruit of comparatively poor quality, which is on that account almost entirely used for home consumption * * *. The fruit exported from the oases, being entirely disposed of in the native markets of the Nile Valley, is packed and sewn up without any special care in palm-leaf baskets. For local use small quantities of selected fruit are frequently preserved in a moist state in earthenware jars.

No offshoots under the name "Wahi" were ever imported for planting in this country.

IMPORTATIONS OF THE SAIDY DATE UNDER VARIOUS NAMES.

The first offshoots of the Saidy date secured under that name were received July 26, 1904, through H. A. Rankin, of Fayum, Egypt, who acted under instructions from David Fairchild, Agricultural Explorer of the Department of Agriculture. Mr. Rankin arranged with a Greek merchant, who was going into Baharia with a trading caravan, to bring these shoots. Of a lot numbering 29, there were 15 shoots of the Saidy variety. These were given S. P. I. No. 11485, as recorded in Bureau of Plant Industry Bulletin 97 (Inventory No. 11), issued March 15, 1907.

In February, 1905, Mr. Rankin, under instructions from Mr. Fairchild, made a journey from Alexandria to Siwa Oasis, where he purchased 114 offshoots, comprising six varieties, of which 42 offshoots were of the Saidy variety. These were received in New York on March 23, 1905, and the "Saydy" offshoots were listed in Inventory No. 11 under S. P. I. Nos. 15215 and 15220.

In October, 1901, the Department of Agriculture had received through Mr. Fairchild, from Em. C. Zervudachi, a Greek merchant of Alexandria, a consignment of offshoots of six varieties from Lower Egypt, which included several labeled "Oga de Bedrichen,"[9] which were designated S. P. I. No. 7632. Three trees of this lot can still be identified in the cooperative Date Garden at Tempe, Ariz. They are in no way to be distinguished from the Saidy trees from Baharia and Siwa procured by Mr. Rankin. In 1910 the writer prepared a general description of the character of these "Oga de Bedrichen" trees at Tempe, Ariz., which is here quoted from his unpublished manuscript notes.

OGA DE BEDRICHEN, S. P. I. NO. 7632 (28).

Trees of vigorous growth with very thick trunks and long, stiffly outcurved leaves, which give the mature top a spread of about 80 degrees. The very broad, thick leaf bases have a clear exposure of 12 or 15 inches below the first spines and taper gradually to the heavy rib, which is strongly rounded dorsally and has wide lateral faces. The rib diminishes steadily to a quite slender apex; the outcurve is mostly made at the base, the body of the blade being rather stiff, but with graceful flexibility at the top.[10]

A summing up of the leaf characters discloses, first, a lower leaf armed with powerful spines set at very effective angles for defense; second, a broad blade due to the rather long pinnæ and strong axial spread of the introrse and retrorse pinnæ classes, with a deep valley of the antrorse pinnæ through the broader part of the blade; but in the outer 3 or 4 feet all classes spread out

[9] The spelling "Bedrichen," is retained to designate the trees grown from this consignment. The place name is "Bedrashen."

[10] For a manual of the terms used in describing date-leaf characters, see "Botanical Characters of the Leaves of the Date Palm Used in Distinguishing Cultivated Varieties," Bulletin 223, United States Department of Agriculture, by the writer of this bulletin (21).

to a nearly flat blade with broad, coarse, overlapping pinnæ. The uncured fruits are about 1¾ inches long, 1¼ or 1⅜ inches in diameter, irregularly egg shaped. They are a rich orange color in ripening, dull tan when mature. The thick amber-colored flesh is a little coarse, but very rich and luscious. The seeds, about 1 inch long by three-eighths of an inch broad, have mostly rounded ends, a rather shallow ventral furrow, and the germ pore nearly central. In the heavy soil and unusual moisture conditions, together with the cooler climate of the Tempe Garden, this variety has perfected but little edible fruit, and the ripening has been very uneven.

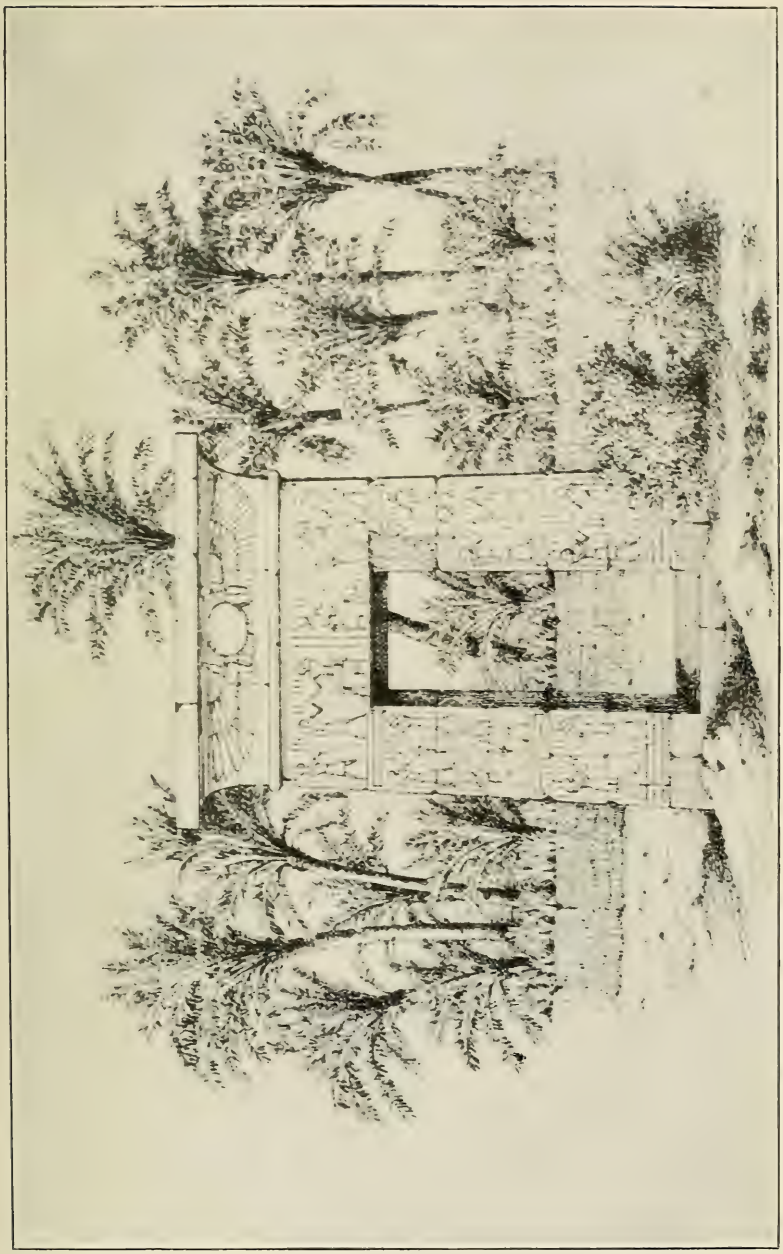
By the use of this description the writer identified the "Oga de Bedrichen" trees at Tempe, Ariz., with trees called "Sewi" which he examined in September, 1913, in the gardens at Bedrashen and later in the section about Hawamdia and Abu el Nemrus. (Pl. II, Figs. 1 and 2.)

During the following October the writer visited Kharga and Dakhla Oases of western Egypt, and there observed the very close similarity of the Saidy variety, the great commercial date of the five western oases, with the "Sewi" of Gizeh Province. Near Kharga village are the imposing ruins of the temple built by Darius I at Hibis, about 500 B. C. (Pl. III.) It was from luxuriant Saidy palms growing beside this temple gateway that the writer made the first critical study of the leaf and fruit characters which was to establish the identity of the Saidy with the "Sewi" variety of Gizeh.

It was also during a stay of a week in late October at Rashida village in Dakhla Oasis, a center of extensive Saidy plantations (Pl. IV, Fig. 1), that another interesting bit of information was picked up. The date harvest was nearly completed, and a camel caravan from each district was starting for the river by the "Derb el Tawil" or "Long Road" nearly every night. In a conversation the Sheik Abu Bakr, the omda of the village, expounded the importance of the Saidy variety to the western oases substantially as follows:

This date is the one marketable commodity we can depend upon in all of these oases. We have the same variety in all of them. We have it in Siwa, away to the north. We have it at Baharia, very many trees. We have it at Farafra. We have it, as you see, here in Dakhla, more than anywhere else. We have it at Kharga, where you came through. We can raise enough rice and wheat for our bread, but we must have something to sell to get sugar and tea and cloth and some money to pay our taxes, and this date is what we all depend upon. We all call it by the same name, the Saidy, but when these Bedouin traders get over to the valley with it they call it the "Wahi."

It was thus through this conversation with a friendly oasis sheik, 200 miles back in the Libyan Desert, that the location and the true identity of the long-sought "Wahi" date was learned after 12 years of search. The solution of the puzzle is really quite simple. The Arabic for an oasis is "wâh," feminine "wâhât"; thus Dakhla, in an Egyptian census of taxable date palms, is "el Wahat el Dakhla." The Bedouin traders, ever fond of making a mystery of where they obtain their goods, call this date in the valley bazaars "Wahi," vaguely, the date from "el wâh," or the oasis, so that the name Saidy is quite unknown to the Egyptian public. In the same manner Hayany dates grown in the district near Birket el Hadji, the "Pool of the Pilgrims," on the borderland between the delta and the hot sand dunes of the Arabian Desert, being the earliest of that variety to reach the market, were known as "Bala Birket el Hadji."



TEMPLE BUILT BY DARIUS I AT HIBIS (NEAR KHARGA VILLAGE), KHARGA OASIS, EGYPT, ABOUT 500 B. C.

Photographed by E. L. Crandall, from an old print.

FIG. 1.—SAIDY DATE GARDEN NEAR THE VILLAGE OF RASHIDA, DAKHLA OASIS, EGYPT.

Photographed by the Author in October, 1913.

FIG. 2.—A YOUNG SAIDY TREE IN FRUIT AT THE COOPERATIVE DATE GARDEN, TEMPE, ARIZ., IN OCTOBER, 1915, FRUIT NOT YET MATURE.

FIG. 1.—PACKING SAIDY DATES IN UPPER GIZEH PROVINCE, EGYPT.

FIG. 2.—A CAMEL LOAD OF SAIDY DATES AS THEY ARRIVE IN FAYUM EGYPT, FROM THE OASIS OF BAHARIA.

Photographed by the Author in November, 1913.

FIG. 1.—A CAMEL LOAD OF "GERIDEH," OR RIBS OF THE DATE-PALM LEAVES, USED FOR MAKING PACKING CRATES, MARG, EGYPT.

Photographed by the Author in April, 1920.

FIG. 2.—DATE-PALM CRATES AFTER UNPACKING AT THE GOVERNMENT DATE GARDEN, INDIO, CALIF.

Photographed in September, 1920.

Zervudachi, mistaking this local description for the real name of the variety, shipped Hayany offshoots to Mr. Fairchild under the name of "Birket el Haggi," and it was not until the writer's visit to Cairo in September, 1913, that this confusion was straightened out, though the Hayany is by far the most abundant date in the delta region of Egypt.

The identity of the "Wahi" with the Saidy was further confirmed in the following November, when the writer visited Fayum in company with T. W. Brown, horticultural director of the Egyptian Ministry of Agriculture. At Abshawa, or Ebchawai, a village in western Fayum, a Bedouin trader was found just in from the desert with a small camel train loaded with dates which he called "Wahi." (Pl. V, Fig. 2). At first he claimed that he had come from the Siwa Oasis, though every one in the village knew that he had never been there, but under the cross-questioning of the omda, or village headman, admitted that he had bought his dates in Baharia Oasis, 6 days' journey from Fayum. A bag of his dates was purchased, and examination showed them to be identical with the Saidy dates seen in Dakhla. These dates were shipped to Mr. Fairchild at Washington, who positively identified them with the "Wahi" dates he had seen in Fayum 12 years earlier.

Thus the identity of the "Wahi" and Saidy was established. It may be interesting at this point to compare the description of the Saidy date of the oasis and the "Sewi" dates of Gizeh, as prepared by the writer from notes made in the gardens in the autumn of 1913 and published in 1915 in Department Bulletin No. 271 (*22*).[11]

SAIDY.

(Saidi, Wahi.)

Trees with heavy trunks and stiffly spreading leaves 10 to 14 feet long, the heavy ribs with very broad bases.[12] There is a space of clear petiole of 12 to 15 inches below the first spines. The rib is strongly rounded dorsally and tapers but slowly, its outcurves being stiff rather than graceful.

The spine area is from 2½ to 3½ feet, the spines of medium weight or quite heavy, placed singly and rather scattered, from 2 inches long below to 7 or 8 inches in the upper area, and passing into a stiff ribbon pinnæ or spike pinnæ 20 to 24 inches long and one-half to three-fourths of an inch wide. The normal pinnæ following these at 4 to 5 feet are 20 to 24 inches long and 1¼ to 1⅝ inches wide, but dropping steadily in length to 12 to 14 inches near the apex. Their greatest width of 1½ to 1¾ inches is reached at about three-fourths of the blade length from the base. The pulvini are unusually heavy, deeply cream colored, or slightly brownish in exposed places. The pinnæ are rather coarse and harsh, 0.018 to 0.019 of an inch or sometimes 0.025 of an inch thick and conspicuously bluish green with a heavy waxy bloom. This bluish green color is very noticeable when the leaves are seen in a mass.

The 4-ranked arrangement of the pinnæ is conspicuous, and the narrow axial angles and strong angles with the blade plane formed by the lower antrorse pinnæ give the leaf a bristling and formidable appearance. The valley is close and narrow nearly to the apex of the blade. The pinnæ groups are of the normal types till quite near the apex, and the paired groups of the antrorse-retrorse type are largely in the majority.

The orange-yellow fruit stalks are strikingly long, of medium weight, or rather heavy in some cases.

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[11] Since this bulletin is out of print, it seems desirable to quote from it at length those parts which bear upon the identity of the dates which have gone under the names "Wahi," "Oga de Bedrichen," and "Sewi."

[12] Notes in parenthesis following color terms in this and following pages refer to plate numbers in Color Standards and Color Nomenclature, Robert Ridgway, Washington, 1912.

The fruit[13] is 1½ to 1⅝ inches long, seven-eighths of an inch to 1 inch broad, blocky, with broad square base rounding to a broad obtuse apex. The skin is rather coarsely wrinkled both longitudinally and transversely and partially loosened from the flesh. The darker portions of the flesh have a translucent appearance and are nearest to "liver brown" (R. XIV)[14] in color, with a delicate lavender bloom.

A basal zone of about one-fourth the length of the fruit is a "tawny olive" (R. XXIX) and is opaque in appearance. The flesh is three-sixteenths of an inch thick, firm, slightly granular, somewhat sticky; an outer zone of one-third of the thickness is of the exterior color, while the nearly transparent inner portion is close to "olive ochre" (R. XXX), with a little more suggestion of green.

The flavor is heavily sweet, rich, and a little cloying, but of the quality usually sought after by date purchasers in this country. After being packed seven months the quality is in no way impaired, and where not reached by weevils these dates would sell as well as at Thanksgiving time. No variety has been tried that stood the test better.

The seeds are five-sixteenths of an inch to 1 inch in length, three-eighths of an inch broad, smoothly rounded, the germ pore nearly central, the ventral furrow narrow and shallow, the color close to "tawny olive" (R. XXIX).

The fruits, packed in paper boxes and rather dry, averaged 35 to 40 to the pound. The percentage of seed weight to the total weight of fruit is 11.6, a ratio too high to mark this date as of absolutely first quality, yet with its other good qualities a great deal can be allowed in this respect.

These fruits ripen in the heat of the Libyan oases in October. Whether they will find sufficient heat for their perfection in any portion of the United States outside of the Salton Basin is perhaps doubtful. Temperature records of only one of these oases have been kept. A record of seven years at Dakhleh (Table I) shows a mean annual temperature of 74° F., which is slightly higher than that of Palm Springs, Calif.; and for the growing months of February to October, inclusive, a mean of 78.40° F. The summation of heat units is about the same as that of Tuggurt (Tougourt) in Algeria, which suggests about the same temperature requirements as for the Deglet Noor. This indicates that this variety may be expected to reach maturity in the United States only in the heat conditions afforded by the Salton Basin of California or in the hot lower portion of the Colorado Valley from Needles to the Mexican line.

This variety, as seen by the writer, is the great export date of Khargeh and Dakhleh Oases, and Sheik Abu Bakr, of Dakhleh, is authority for the statement that it is the chief date of the entire chain of oases of the Libyan Desert, from Siwah at the northwest, which lies about 400 miles southwest of Cairo, through Baharieh, Farafreh, and Dakhleh to Khargeh, the most southeasterly, lying 120 miles due west of Luxor.[15]

They have together an extreme north to south range of about 300 miles through a practically rainless region of dry air and intense desert heat. Siwah is said to be 78 feet below sea level. The other oases of the chain lie at elevations ranging from near sea level to three or four hundred feet above. Only Khargeh has railway connection with the Nile Valley; from the other oases the dates reach the Nile Valley by camel caravans commanded by Bedouin traders who buy the entire export crop of the desert people at their gardens.

The common occurrence of this date as the leading variety of the widely detached oases, while it is unknown in the Nile Valley,[16] suggests that they have had it in possession a long time, perhaps dating back to a period when allegiance to the Egyptian Government was not acknowledged and when communication was much more free and regular by the desert trails between the oases than that between the oases and the Nile Valley.

In the enumeration of the taxed date palms of Upper Egypt for 1907 the oasis of Baharieh is credited with 98,996, Dakhleh with 106,344, and Khargeh

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[13] Notes made near the Temple of Nadurah, Khargeh Oasis, Oct. 8, 1913.

[14] Described from fruit packed in cartons at Sheik Abu Bakr's, Rashida, Dakhleh Oasis, Oct. 18, 1913.

[15] Siwah is approximately 25° 30′ east of Greenwich and in 29° north latitude. Baharieh is crossed by the meridian of 29° and lies just north of 28° latitude. Farafreh lies close to the intersection of the meridian of 28° and the parallel of 27°. Dakhleh lies about equally on either side of the meridian of 29° and at about 25° 30′ north latitude. Khargeh lies with its greatest extent north and south about 30° 40′ east and from 24° 30′ to 26° north latitude.

[16] Unless the Siwah of Gizeh Province proves to be identical

with 65,521, or a total of nearly 271,000 trees. Siwah and Farafreh are not reported.

From observations in Khargeh and Dakhleh and from the crop seen coming in from Baharieh, the writer is satisfied that considerably more than half of the trees in these three oases are of the Saidy variety, so that a low estimate would give 150,000 or 200,000 of these without including Siwah Oasis, where it is known to be the chief tree.

A very interesting bit of exploration history attaches to the procuring of this variety. David Fairchild, in an agricultural exploration of Egypt in 1901, purchased in Fayum a quantity of dates which he regarded as the finest he had seen in Egypt and which he was told were "Wahi" from the village of Siwah in the oasis of Baharieh. Though it was known to Mr. Fairchild that the term "Wahi" had reference to the oasis, it was supposed for many years that this was the varietal name of the date, and three different men had been dispatched with commissions from the Office of Foreign Seed and Plant Introduction to procure offshoots of this desirable variety. During the writer's trip to Dakhleh Oasis he learned from Sheik Abu Bakr that Saidy, the export date of the Libyan oases, is sold by the Bedouin traders when they reach the Nile Valley as "Wahi," the date from "el Wah," or the oasis. Samples of the fruit, purchased in the markets of Wasta, in Fayum, and directly from the traders under the name of "Wahi," proved perfectly identical with samples of Saidy brought from Dakhleh and Khargeh, establishing beyond question the Saidy as the long-sought "Wahi." Though 108 Saidy offshoots were purchased in Khargeh on this trip, the first introduction of Saidy offshoots dates from the purchase through Mr. H. A. Rankin, S. P. I. No. 11485, in 1904, said to be "from Fayum." As this variety is not known in the Fayum country, it is probable that Mr. Rankin secured the offshoots through Bedouin traders from the oasis of Baharieh, between which points there is constant traffic.

Another interesting phase of the whole discussion is the very close resemblance, if not the absolute identity, of the Saidy with the Siwah grown in the upper sections of Gizeh Province.

SIWAH (SIWI).

(Notes made near Hauamdiyeh, November 5 and 17, 1913.)

Trees of the Siwah date have large heavy trunks with coarse scales from the leaf bases and heavy, stiffly spreading tops. The leaves are 14 to 15½ feet long, with very heavy bases, strongly rounded lower rib, which tapers gradually but still remains stiff and heavy at the apex. The spine area is from 2½ to 4 feet, the spines very strong and heavy, bluntly acute, from 2 to 8 or 9 inches long. The stiff, coarse pinnæ following these are 24 to 29 inches long and 1 to 1¼ inches broad. They diminish regularly in length toward the apex and increase in breadth up to 10 or even 11 feet from the base, being usually 17 to 20 inches long and 1¾ to 2 inches broad at 8 to 10 feet from the base and 11 to 14 inches long and 1¼ to 1½ inches broad at the apex. Many of the upper pinnæ have the proximal fold broadened into a wing and are decurrent. The pulvini on the spines are unusually heavy and dark cream colored, being somewhat lighter on the less exposed pinnæ. For the first 6 feet of the blade the pinnæ comprise only the antrorse and retrorse classes in the paired antrorse-retrorse groups, above which the introrse pinnæ appear, and also the triple (antrorse-introrse-retrorse) groups with a few quadruple (antrorse-introrse-introrse-retrorse) groups. In the outer 2 feet of the blade the introrse class predominates, or all classes become merged. The 4-ranked arrangement of the pinnæ in the blade is strongly maintained, but is especially pronounced in the lower portion, where the bristling ranks of the antrorse pinnæ vary strongly from those of the retrorse and give to the leaf a strong attitude of defense. The remarkably long and heavy orange-colored fruitstalks of this variety are almost identifying in their character. They may be 2½ inches in diameter and 50 to 60 inches long to the fruiting head, or portion bearing the strands, or "shamrokh." The fruiting head is 16 to 24 inches long, bearing strands 24 to 40 inches long upon only the outer 12 to 18 inches of which the fruit is borne, the basal portion being straight and irregularly four sided.

The fruit is 1⅜ to 1½ inches long, 1 inch broad, oblong or slightly broadest a little beyond the middle, with a rather square blocky base and obtusely rounded apex. The color of the fruit on the tree is a brilliant yellow, not far from "wax yellow" (R. XVI) or "light cadmium" (R. IV). The fruits

are picked before they are fully ripe and are dried in the sun on a hard earthen floor, or the floor may be spread with a thin layer of date leaves. The first quality of fruit ripens to a color near "hazel" (R. XIV) or "tawny" (R. XV), but it is semitransparent except the basal portion, which is often opaque and of a "honey yellow" or "chamois" color (R. XXX). Fruits of a very good quality may be considerably darker, close to "bay" or "chestnut" (R. II), but either class held against the light will show the seed through the flesh quite plainly. The skin is very thin and transparent, and the outer portion of the flesh is of the same shades given for the outside appearance, while the inner flesh is considerably lighter. In good "agwa" that has been packed several months the outside of the fruit is shiny, as though dipped in a sugar sirup, and is a little sticky.

The flesh is less sticky than the outside and a good deal granular. The flavor is a rich sugary sweet, with a suggestion of caramel, and very agreeable.

The seeds, large for the size of the fruit, are about three-fourths of an inch to 1 inch long, three-eighths of an inch broad, roundish in cross section, and may be called oblong oval in form, a little broader in the middle and with broadly rounded ends. The germ pore is about central, the ventral surface a little corrugated, the furrow narrow and shallow. The color is close to "wood brown" (R. XL).

When sufficiently cured the dates are packed solidly into strong, deep, circular baskets made from the braid of date-leaf pinnæ sewed spirally, and a cover of the same material is stitched closely on. The whole mass thus inclosed becomes sealed with the exuding sirup of the sticky dates and is practically airtight. If cleanly and sanitary methods could be followed, there is no doubt that this method of packing is an excellent one, and there is reason to believe that a curing process goes on in the mass which gives a flavor and texture of flesh not secured when the individual dates are packed in their natural shape in paper cartons without compressing and so exposed to the air.

The rather large seed is all that prevents this date from being classed as a strictly first-class variety, judged by its actual merits as a date. That the product that goes on the market is not above third class needs only a view of it in the market stalls to prove. One has but to see the yards and the curing and packing in progress to be convinced that such a product is the only possible result of the antiquated and filthy, not to mention insanitary, methods employed. Dried on the bare, dust-covered ground or on a floor thinly spread with date leaves, covered with flies, swept with the dust of passing traffic, finally tramped with the naked feet into the huge date-leaf sacks, the writer was not surprised to learn that the wholesale price realized for these dates by the grower is only about 4 or 5 millièmes to the rotl, the equivalent of 2 or 2½ cents per pound.

In December the retail price of the Siwah in the native markets of Cairo was 1 piaster per rotl, while at the same time in the best fruit and provision stores, patronized by European customers, there was an active trade in the Algerian Deglet Noor, in fancy packages labeled "Dattes Muscades," at prices the equivalent of 5 piasters per rotl. From samples of Siwah dates obtained from private sources, carefully selected and packed for home use, the writer is convinced that the first quality of dates, packed in a modern and attractive way, would be competitors with the Algerian dates on at least an equal footing and would be the choice of many people of refined taste. Of course, not all of the Siwah crop could be converted into a first-class pack under the best of conditions, but a sufficiently large proportion, with proper methods, could be brought up to the first quality to make the difference in price between 1 piaster and 5 piasters per rotl run into a good many thousand pounds sterling for a year's output. What the French in Algeria and Tunis have done to improve the date output of those countries, what is recently being done with the dates of the Persian Gulf region, ought not to be beyond accomplishment for Egypt with such dates as the Siwah and the Saidy for a foundation.

A question of nomenclature comes in here which is rather typical of the whole date situation in Egypt, and arises from the habit of the people of giving to a date the name of the locality from which it is brought, as "Wahi" for any date from the oases, "Yemeny" for dates from the Yemen district of Arabia, etc.

In the shipment of date offshoots received by Mr. Fairchild in 1901, through Em. C. Zervudachi, of Alexandria, one lot, given the S. P. I. No. 7632, was labeled "Oga de Bedrichen" and in some of the lists this name became transformed into "Oga de Bedreschen." Two trees under the above number and

one received without a label were recognized by the writer as identical, and careful notes were made of the leaf and fruit characters, all of which were strongly marked and characteristic.

As no such name occurred in any of the published lists of Egyptian dates, there was naturally considerable interest in the true identity of so conspicuous a variety. Consequently, on arriving in Egypt one of the writer's earliest excursions from Cairo was to the native village of Bedrashen (variant spellings, "Badrashen" and "Badreshein"), a prominent date growing and shipping point on the west bank of the Nile, about 10 miles above Cairo. It is the stopping point for excursionists to the historic site of ancient Memphis and Sakkara, and perhaps no spot in the Nile Valley has witnessed more of the glory of ancient Egypt than this. At the present time there are no more magnificent date groves to be found in Egypt than those that surround this town, Hauamdiyeh, and a number of other villages between Bedrashen and Gizeh. The soil is a rich sandy loam, capable of producing heavy crops of general produce, and maize is frequently grown beneath the date trees. Going out among the date growers and inquiring for a variety named Oga de Bedrashen, brought the unvarying response that they knew of no such variety. They had only Siwah and Amhat, a few Hamrawi, and some "balady," their name for dates of local origin, or seedlings. On looking over their garden the young trees of the Siwah had a familiar appearance, and a later visit gave time for the study of the leaf and fruiting characters in detail. Only one conclusion could be reached—the variety we had received under the name of "Oga de Bedrichen" is no other than the Siwah, the leading variety of the Bedrashen and Hauamdiyeh district and the chief packing date of Upper Egypt. The mudirieh of Gizeh has 435,000 taxed date trees, and at a rough estimate 100,000 of them are of the Siwah variety. With the exception of a few trees that are being planted in Fayum, there seems to be little known of this variety outside of Gizeh Province, and within that it is chiefly confined to the section south of Gizeh station and to a district on the west side of the valley and north of the pyramids. Of its origin or the date of its introduction into this district, nothing could be learned. The name at once suggested an introduction from the oasis of that name. But unlike Dongola Province, where they preserve a distinct tradition of having obtained their date varieties from the Sukkot country, these people have no record of the introduction of the Siwah into their country, and they insist that it originated there.

The situation is further complicated by the fact that there is an exceedingly close resemblance between the Siwah and the Saidy, the great export date common to the entire chain of oases of western Egypt, from Siwah at the northwest, to Baharieh, Farafreh, Dakhleh, and around to Khargeh. A most careful comparison of all the characters of trunk, leaf, and fruiting stalk fails to show points of constant difference between these varieties, unless it is in the thickness of the fruiting stalk, which, on the whole, seems to be lighter in weight in the Saidy than in the Siwah. How growing in the same soil conditions would affect them in this respect can only be determined by trial. The fruits are so closely related in character that the oasis Saidy variety, as packed and brought to the Nile Valley, shows no constant differences that will distinguish them from the Siwah of Bedrashen, though individual lots may vary considerably. The question again arises of how the varieties would behave if grown side by side in identical soil conditions. The rich soil of Bedrashen and Hauamdiyeh might produce somewhat different results in a variety than would be produced in the rather poor, sandy soils of Khargeh and Dakhleh Oases, in which the writer studied the Saidy. Trees of "Saydy," S. P. I. No. 11485, fruited in 1912 in a very sandy soil at the Mecca Date Garden in California, and were considered by Bruce Drummond, in charge of the Indio and Mecca Date Gardens, to be identical with the "Oga de Bedrichen" (Siwah) of Tempe. The writer at first concurred in this opinion, but with a more detailed examination of the Mecca plants concluded that they were distinct. After seeing both varieties, as grown in Egypt, to still regard them as distinct, with so many points of identity, can only be accounted for in one way. The Siwah, from its narrow dissemination, is possibly the younger variety and a seedling springing from the Saidy, the fruit of which has found its market in the valley for many years. Analogy for an even closer resemblance of a seedling to its parent is found in James Reed's "Pioneer" seedling of the Deglet Noor, produced at Thermal, Calif.

There is another point that makes it of importance that the Saidy and the Siwah should be tested in identical situations. The ripening of the two varie-

ties is about simultaneous, in spite of the remoteness of the localities and marked difference in the temperature. At Dakhleh the mean temperature for the nine months of the growing period, from flowering to date harvest, February to October, inclusive, is 78.40° F. That of Heluan, the nearest record point to the Siwah date field, for the same period is 72.54° F., or 5.86 degrees lower. As shown in Table I, the summation of heat units from May to October, inclusive, is 1.079 higher at Dakhleh than at Heluan. These figures, showing so many more available heat units for the Saidy than for the Siwah, would lead us to expect it to ripen earlier, provided the varieties are identical, and they offer the strongest argument presented in support of a varietal difference between the two.

The maximum yield of Siwah at Bedrashen is given as 100 kantars of 320 pounds to the feddan, practically 1 acre, or often only 60 or 70 kantars. The maximum yield would then be 32,000 pounds to the feddan, which, allowing 100 trees to the feddan, would give a yield of 320 pounds to the tree. At 80 piasters per kantar the money return would be £80, or $400. Placing the yield at 60 kantars, the more probable average, the crop would be 19,200 pounds, or 192 pounds to the tree. At the minimum price of 60 piasters per kantar the return would be £36 to the feddan, or $180 per acre; 70 kantars, a medium yield reported, would equal 22,400 pounds, or 224 pounds to the tree, a not unreasonable yield. This, at 80 piasters, would give £56, or $280 to the feddan or acre. This, it should be remembered, is on land valued at the rate of £100 to £200 per feddan.

T. W. Brown (*6*), whose valuable paper, published in 1916, is the most reliable and technical study of the date culture of Egypt yet made, considers the "Saidi" and "Siwi" as separate varieties, though admitting that they are "very closely allied." He says, "It has been suggested that the difference of the fruit of the two kinds is due to differences of climate. Is it not more probable that the Siwi has originated from seed of the Saidi?" However, no constant differences in botanical characters can be found to support the idea that the "Sewi" of Gizeh is a seedling of the Saidy of the oasis. In the writer's judgment the migration by offshoots of Saidy from Siwa Oasis is the more probable explanation. Culturally and commercially there seems to be no discernible difference. The young Saidy trees from the importations of 1904 and 1905, now growing in the Cooperative Date Garden, at Tempe, Ariz., are in no way to be distinguished from the trees of "Oga de Bedrichen" imported in 1901. The "Oga de Bedrichen" trees have been identified with the "Sewi" of Bedrachen and Hawamdieh. There can be no doubt, therefore, that the Saidy variety of the Libyan oases and the "Sewi" of Gizeh Province are one and the same. Any slight differences can be explained by difference in soil, water supply, and atmospheric temperature and humidity. Their positive identity under similar environment in Arizona and California seems to be no longer in question. The name "Sewi," indicating its origin in the Siwa Oasis, is no more than must be expected. With the bringing into the Nile Valley perhaps of caravan loads of Saidy dates from the oasis of Siwa for centuries past, what could be more natural than the desire to possess and cultivate this excellent and celebrated date in the Nile Valley? Merchant caravans made their headquarters at Kerdaseh and other villages along the desert border of the Nile bottoms opposite Cairo. Twelve days from Siwa in February, their favorite month for moving offshoots, would put a camel load of Saidy offshoots from Siwa into the rich bottom lands of Gizeh.

In November, 1921, the writer visited the little Bedouin village of Abu Roash, a mile beyond the ruined pyramid of that name. It is built against the rocky base of Gebel Abu Roash, by some ancient

cave tombs, yet the pyramid range of flood basins brings the Nile flood water to it. The camping places of the Siwa caravans are all around, and many of the men have been over the desert trail.

The first man met was a Bedouin who had a few palms and a little garden which he watered from a shadoof. One of his "Sewi" palms, he claimed, went back to the time of Mohammed Ali, which would make it about 100 years old. He said he had been to Siwa and that they had the same palm there. The people in Siwa called it the Saidy. When I asked him if he was absolutely certain that the date called the Saidy by the people of Siwa was the same as the "Sewi," he declared that he was and expressed astonishment that there could be any doubt about it.

Some time later at the esbet, or village, where a man told me that the first caravan with dates from Siwa had arrived and was encamped some distance away, he showed me a handful of the dates he had obtained from the caravan and insisted that they were "Sewi," though the dates were quite unmistakably what we know as the Saidy.

When these Bedouins, who have known this caravan trade from boyhood, assume it as a matter of common knowledge that the dates of the wahat (Saidy) and those of the Gizeh ("Sewi") are the same, I believe it leaves no reasonable doubt of their being one and the same variety.

In December, 1921, further confirmation of this was secured at Kirdasa, a native village on the border of the desert, about 5 miles northwest from the Pyramids of Gizeh. Its territory lies above the last canal, but much of it is flooded when the irrigation basins are filled. The chief industry is date growing, and the Amhat, Sewi, and Hayany are its chief varieties. The omda of the village states that they have about 20,000 trees of the "Sewi" variety. The village is near the mouth of Wadi el Natrun, through which the great caravan trail from Siwa Oasis and westward has passed for many centuries. It was from "Kardassi" that Frederick Horneman set out with a company of merchants of Aujila in September, 1798, becoming the second modern European explorer to reach Siwa. The father of the present omda had made the journey to Aujila, and the omda and his brother, 75 years old, have been familiar with this caravan traffic from boyhood, the great camping places of the caravans being near their home. They stated that while the caravans brought a few dates of what they regard as the choicer variety, the Ghrasali, the great volume of the export dates from the wahat, or oasis country, is of the Saidy variety, known to the merchants as the "Wahi," because it is the date they obtain from the wahat. Both men asserted positively that the Saidy which the caravans brought from Siwa Oasis and the "Sewi" of their "belad" or country were the same.

It was their opinion that the "Sewi" came originally from the wahat, probably from the "belad" of Siwa. They believed that the variety had been in their village as much as 150 years, and they themselves had trees that they thought were more than 100 years old. The older man pointed out trees which he said were as tall as they now are when he was a boy. Though they were inclined to believe that the "Sewi" variety had come from seed instead of "shettla," as they had never heard of any "shettla" being brought

from Siwa Oasis, they admitted a little later that they had trees of the Ghrasali from "shettla" that had been brought from Siwa, thus establishing the point that "shettla" could be brought from there and live.

The writer's trip to Egypt in 1920 resulted in the importation by the Department of Agriculture of 1,000 authentic Saidy offshoots from Kharga Oasis and of 1,000 shoots, now known to be of the same variety, carefully selected from the best plantations in the section about Bedrashen in Upper Gizeh. Plates VI and VII show materials and methods of packing these offshoots for shipment to America. All of these trees have been planted in quarantine nurseries in the Coachella Valley in California. In the fall of 1921 the writer returned to Egypt and by the middle of March, 1922, shipped to the United States about 7,000 offshoots of the Saidy variety, most of which were obtained in the vicinity of Gizeh. About 650 were secured from Kharga.

A summary of the importations of the Saidy date by the Department of Agriculture, beginning with the original shipment of "Wahi" fruits, is as follows:

As "Wahi" (fruit only), from Fayum, said to come originally from the oasis of Baharia, by Fairchild, S. P. I. No. 7001, in 1901.
As "Oga de Bedrichen" (a few offshoots), from Hawamdia, by Zervudachi, S. P. I. No. 7632, in 1901.
As "Saydy" (a few offshoots), from Baharia, by Rankin, S. P. I. No. 11485, in 1904.
As "Saydy" (a few offshoots), from Siwa, by Rankin, S. P. I. Nos. 15215 and 15220, in 1905.
As Saidy (a few offshoots), from Kharga and Dakhla, by Mason, in 1914.
As Saidy (1,000 offshoots), from Dakhla, by Mason, in 1920.
As "Sewi" (1,000 offshoots), from Gizeh, by Mason, in 1920.
As "Sewi" (about 6,500 offshoots), from Gizeh, by Mason, 1922.
As Saidy (about 650 offshoots), from Kharga, by Mason, 1922.

As can be seen from this summary the Department of Agriculture has received offshoots of the Saidy date from four of the upper oases in the Libyan Desert, and also from the Nile Valley near Gizeh. Offshoots from all five of these localities are now growing in the Government date gardens in the Southwestern States, and their identity and the identity of the Saidy from all of these localities has been established beyond question. Eight importations of offshoots of this variety have been made from Egypt, the first in 1901, the last in 1922, and altogether about 10,000 offshoots of this variety have been brought to the Southwestern States.

Nowhere in Egypt is it possible to see growing side by side Saidy offshoots from all these different localities. This final conclusive demonstration as to the true nature of the 200,000 or more date palms growing in the Nile Valley near the pyramids has been worked out in the date gardens in the Coachella Valley in California, where these offshoots have been proved to be identical with the Saidy variety from the upper oases of the Libyan Desert. The discovery of the true nature of the "Sewi" variety in the Nile Valley has opened up to the date grower a large supply of offshoots where good transportation facilities make them obtainable at moderate prices. It is very doubtful whether enough offshoots could have been obtained from the oases of the Libyan Desert to have permitted the rapid growth of the

FIG. 1.—OFFSHOOTS OF SAIDY DATES AS THEY ARRIVED AT THE PACKING SHEDS OF THE HORTICULTURAL EXPERIMENT STATION, GIZEH, EGYPT.

Photographed by the author in May, 1920.

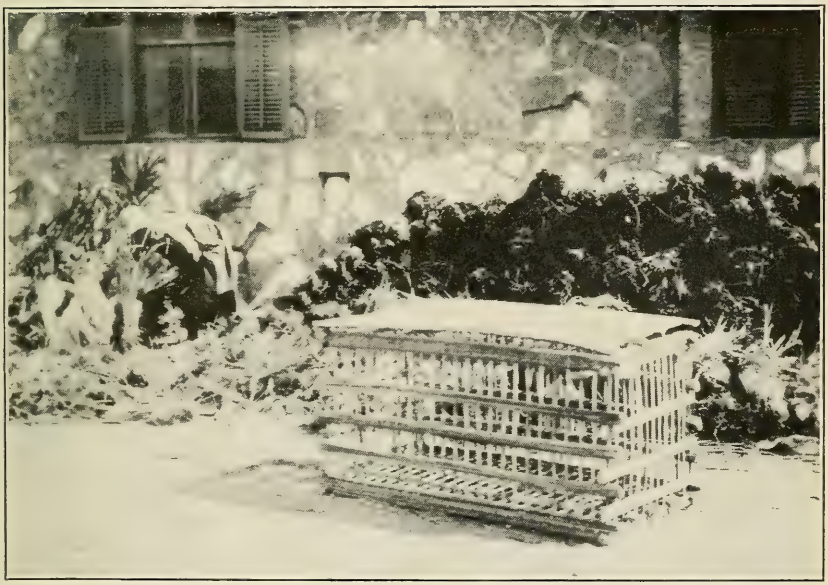
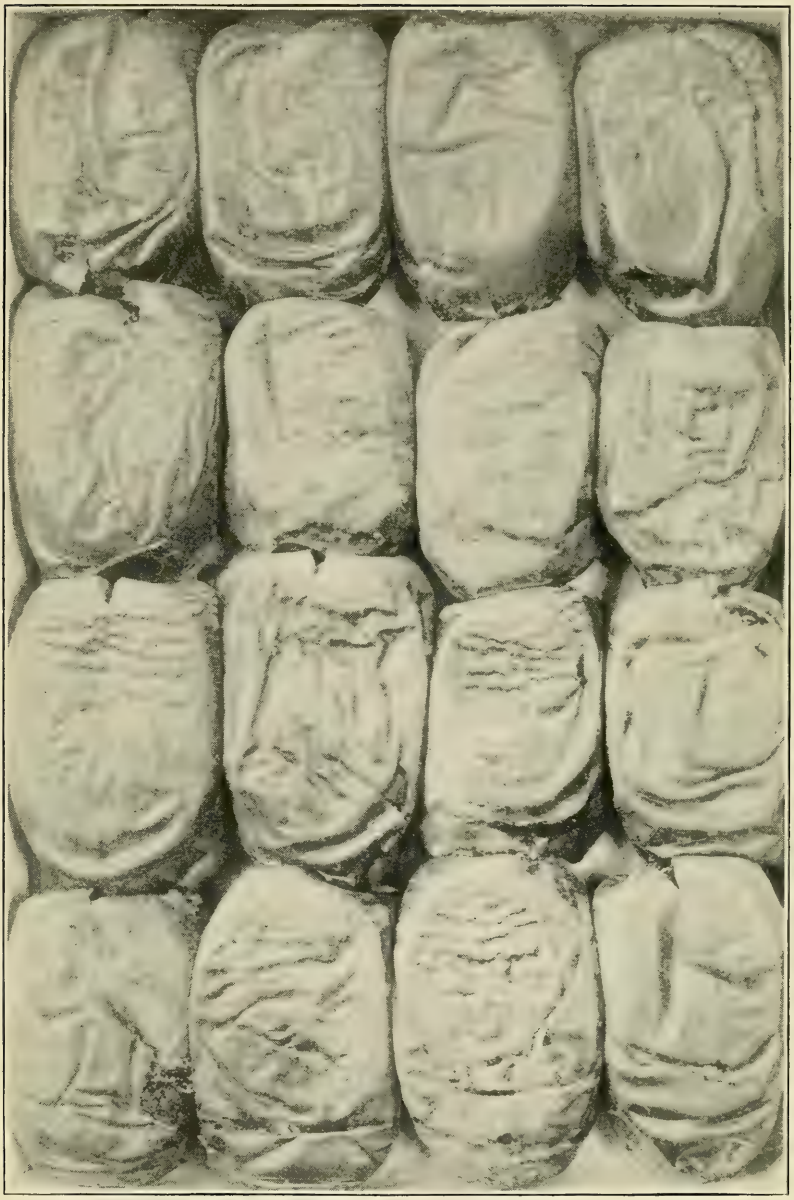


FIG. 2.—ONE OF THE 450 CRATES USED IN PACKING THE 9,000 DATE-PALM OFFSHOOTS SHIPPED FROM GIZEH, EGYPT, TO INDIO, CALIF.

Photographed by the author in May, 1920.



A BOX OF SAIDY DATES GROWN AT THE COOPERATIVE DATE GARDEN, MECCA, CALIF., DURING THE SEASON OF 1920.

Natural size. Photographed by E. L. Crandall, November 16, 1920.

culture of this very promising date on a commercial scale in California within a reasonable time.

THE SAIDY DATE AS A COMMERCIAL VARIETY.

The superior quality of the Saidy dates was recognized by the management of an English concern, The Corporation of Western Egypt, which had established trading stores in Kharga and Dakhla some years prior to 1913. They had packed the fruit in paper cartons under the brand "Dakla Dates" (shown in Pl. XIV, Department Bulletin 271) (*22*) and had shipped the bulk of the crop of one year to England. The enterprise had failed to yield a profit, along with all the other activities of this corporation, in this instance, the managers claimed, owing to the extra cost of moving such packages by the long camel transportation involved.

In the native methods of packing as seen by the writer at Rashida, the dates are gathered before becoming fully ripe and spread in the sun in drying yards, often in the open court of their houses, for several days, being occasionally turned. They were then packed in bags braided from the date-leaf pinnæ, holding about 160 rotls, or pounds, each. (Pl. V, Fig. 1.) After the dates were firmly pressed into these bags, making a compact air-excluding mass, sealed by the slightly exuding sirup of the fruit, a circular piece of matting of the same material as the bags was sewed on as a lid, and the dates were ready for camel transportation, two balancing bags weighing 320 rotls constituting a load for a desert camel. As the oasis people own very few camels, this traffic is chiefly in the hands of the Bedouins, who are shrewd traders, largely obtaining the dates in exchange for goods brought from the valley, thus loading their camels in both directions and making a handsome profit on each transaction.

Egypt, with more than 11,000,000 people to whom dates are a staple article of food and only about 7,000,000 date palms, exports but few dates, only a few hundred tons of the Amri variety, a large coarse date produced in the eastern delta region, being sent to southern Europe, and these are more than counterbalanced by the imports of dates from Algeria and the Persian Gulf and by the dates brought down the Nile from the Sudan. While a few trees of the Saidy variety, from both the oases and the Nile Valley, have borne abundantly at the Tempe, Ariz., garden, but little fruit has matured and none has reached perfection (Pl. IV, Fig. 2). So it was only when trees came into bearing at the Mecca garden and their fruits were cured and packed by the same processes that had been developed for the handling of the Deglet Noor that the splendid market qualities of this new commercial variety were brought to light.

The characteristics of this variety which promise for it such high place among the few great market dates of the world are:

(1) Its quality and flavor. It is a superior date which at once commends itself to lovers of fine fruits. Size and appearance count for little if on trial the quality is found wanting. It is rich in sugar, so rich as to be even cloying to some persons, when freshly packed, though greatly enjoyed by others; but this cloying quality disappears after the fruit has been packed a month or more. By that time the flesh begins to take on a slightly granular character

instead of the more or less tough or "gummy" texture many dates take on with age, and its most rich and satisfying flavor is developed. While the Saidy when freshly ripened does not have the peculiar indefinable aroma and flavor characteristic of the Deglet Noor, on the other hand, it has something which the Deglet Noor has not, viz, an improvement in flavor upon storage, due to a slow granulation of the sugar content, a quality unique with this variety.

(2) Its handsome appearance (Pl. VIII). Its large size, 1⅝ inches long by an inch broad, attracts the eye as a smaller fruit could not. In the package it has a bright "amber brown" color (R. III) or the deeper shades of "chestnut" or "bay." It looks "good to eat." Then its "honey yellow" (R. XXX) colored flesh when broken is equally attractive and fully sustains the expectancy awakened by the outward appearance. The relatively large seed, weighing 20 to the ounce, or 11 per cent of the total weight (against 32 to the ounce in the Deglet Noor) is a technical fault, but one that does not seem to prejudice the consumer.

(3) Packing and keeping qualities. There are many varieties of dates of fine appearance and exquisite flavor which are so low in their sugar content that they are quickly fermentable and must be eaten within a few hours or days at most after they are fully ripe. The Saidy date may be picked from the tree before it is fully mature, sun cured for a few days in drying yards, and after packing will improve in quality for two or three months and remain in perfect condition for more than a year. The processing practiced at the Indio laboratories is a scientific application of the same principles used by the Arabs in sun curing their fruit before it becomes fully ripened, but with sanitary conditions insured and the necessary heat subject to precise regulation. The Saidy responds perfectly to such treatment and is one of the best varieties in retaining its high quality.

While processing and packing experiments have so far been very satisfactory much remains to be done. Indications are that for long keeping, the choicest flavor and texture are best obtained by gathering the fruit while still hard, but with its sugar all laid down, and after the preliminary maturation in air-tight moist chambers with temperatures definitely controlled, packing it in boxes holding 2 or 3 up to several pounds in such a manner that the air is expelled and the fruit sealed by its own sirup. The enzymic action which follows under these conditions seems to effect a more nearly perfect ripening than when the individual fruits are exposed to the air.

(4) Productiveness. The Saidy date is counted as a heavy cropper in the Libyan oases, though data as to the actual yield per tree are not obtainable. Many trees were seen by the writer in the Kharga and Dakhla Oases apparently bearing 200 pounds or more to the tree. Brown (*6*) quotes the yield of Saidy dates in the oases as 90 to 160 pounds per tree. In Gizeh heavily loaded trees of "*Sewi*" were the rule in 1913, and the yields were estimated by the owners at from 200 to 300 pounds per tree. Mr. Brown, as quoted above, reports the average yield per tree of "*Sewi*" in 1914 for a number of trees at each of three villages in upper Gizeh as follows: Kirdasa, 234 pounds; Hawamdia, 321 pounds; Gizeh, 225 pounds; or averaging 260 pounds. The abundant water supply in the upper Gizeh

territory, where the "*Sewi*" is grown, compared with the scant supply from failing artesian wells received by many Saidy gardens in the oases, may in part account for the difference in the yields reported. It should also be remembered that the Saidy reports from the oases are mere hearsay, as compared with definite weight records for one year at Gizeh Province.

(5) Ease of propagation. The Saidy has been found prolific in offshoots, both in the Libyan Desert at Kharga and Dakhla, and in the Nile Valley in upper Gizeh. It produces offshoots abundantly, 20 or more to the tree, in the heavy adobe soil with high ground water and the limit of alkali at the Tempe, Ariz., garden and in the rather sterile beach sand at the garden at Mecca, Calif. Two thousand offshoots, cut and packed in Egypt in May and June, 1920, endured the long transit to Indio, Calif., remarkably well.

This variety promises to be prolific and reliable in the hands of the careful propagator, thus rounding out the list of characters essential to a great commercial date variety.

TEMPERATURE REQUIREMENTS OF THE SAIDY DATE.

Our knowledge of the temperature requirements of the Saidy date is not as clear as could be desired, owing to the lack of weather records adequately covering the territory where it is grown, but enough data are available to afford a basis for some fairly definite conclusions. Egyptian records of the Dakhla Oasis, the home of the Saidy, may be compared with the records at Heluan and Gizeh, approximating the temperature of the Nile Valley district. In the United States carefully kept 10-year records at the Mecca garden are available for comparison with equally careful records of the Tempe garden, where this date has failed to mature.

The only record representing the five Libyan oases is that kept by an Egyptian observer stationed at Mut, the capital town of the Dakhla Oasis, and from the internal evidence of these records as published in the reports of the Egyptian ministry of finance some doubt may be permitted as to their entire accuracy. Moreover, while the Dakhla records may fairly represent Kharga, also in nearly the same latitude, they must be considerably too high for Baharia, situated nearly 200 miles farther north, and especially high for Siwa Oasis, which lies fully 4° of latitude north of Dakhla. Calculated from the gradation of mean temperatures according to official records, from Abbassia to Merowe in Sudan, which show an approximate gain of 1° F. in mean temperature for each degree of latitude, we may expect Baharia and Siwa to have about 3° F. lower means than Dakhla and Kharga. As Baharia is one of the best producing localities for the Saidy date, we may safely conclude that the mean temperatures at Dakhla and Kharga are at least 3° or 4° F. higher than are actually necessary for the safe maturing of this variety. Siwa Oasis, 1 degree farther north than Baharia, has doubtless a slightly cooler climate and is known to produce excellent Saidy dates.

No records have been kept within the area occupied by the Saidy date in upper Gizeh Province, the nearest available being those of the Gizeh post office and of Heluan, across the river from Bedrashen. Gizeh may closely approximate the temperatures of the points in the lower valley lands near the river, as Abu el Nemrus and Hawamdia;

while the Heluan records may better represent Bedrashen and El Marazic and such points on the west side of the valley toward the desert bluffs as Sakkara and Abusir.

Table 1 shows the normal mean, monthly, and maximum temperatures, in degrees F., and Figure 3 the corresponding curves for

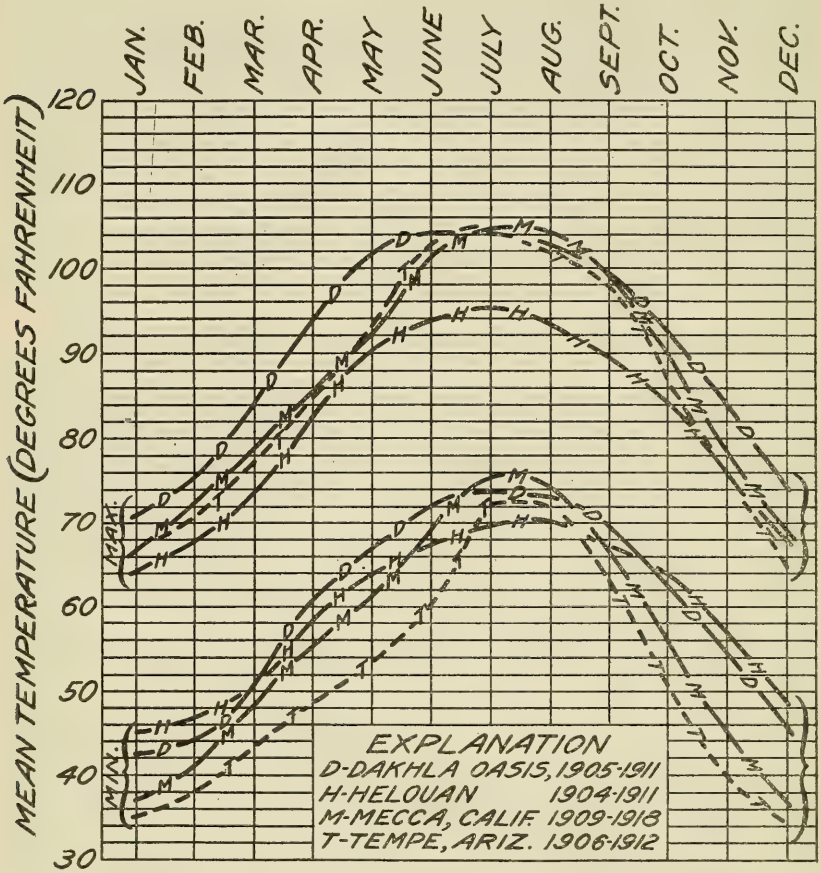


FIG. 3.—Diagram showing the normal monthly mean maximum and mean minimum temperatures, in degrees F., for Dakhla Oasis and Heluan, Egypt, in comparison with the same for Mecca, Calif., and Tempe, Ariz.

Dakhla and Heluan, in Egypt, in comparison with the records for Mecca, Calif., and Tempe, Ariz.

In regard to the behavior of the Saidy offshoots from the Libyan Desert and from Gizeh we have, first, the observations at Mecca and Tempe showing that they display no characters in form and quality of the fruit or in time of maturity by which they can be distinguished as distinct varieties, so they can be treated as one for temperature study; and, second, trees from both these sources have ripened their crops at Mecca with heat units to spare, while at the Tempe garden, though setting abundant crops of fruit, little of it has matured even as far as the processing stage.

Before taking up the study of the maximum and minimum temperatures of the regions involved, it is instructive to plot the monthly

mean temperature curves of Mecca and Tempe on the diagram of means of 12 Egyptian and Sudan stations (Fig. 4), heretofore published (*22*). The difference in the form of these two American curves, as compared with those of Egypt, must at once call attention to the different type of climate into which this date has been transplanted in America. The American curves are higher and narrower toward the apex than any of the Egyptian—that is, the range of monthly means for Mecca is greater than for Dakhla or for any Egyptian station except Aswan, but the extreme summer temperatures are not so long sustained. For the first two months of the year the American stations have the temperatures of the cooler stations of Egypt, but pushing relatively higher and passing all the Lower Egypt stations as the season advances, though escaping the extreme heat of the "Desert tropical" (*22*) stations and of Dakhla from March to June. Through July and August alone Mecca is hotter than Dakhla, and Tempe is equal to it. But the Mecca curve drops below all the upper Nile stations in September to the level of Dakhla and falls below all Egyptian and Sudan stations from October to the end of the year.

TABLE 1.—*Monthly mean, maximum, and minimum temperatures, in degrees F., of Dakhla Oasis and Heluan, in Egypt, and of Mecca, Calif., and Tempe, Ariz.*

Month.	Dakhla Oasis.		Heluan.		Mecca, Calif.		Tempe, Ariz.	
	Maximum.	Minimum.	Maximum.	Minimum.	Maximum.	Minimum.	Maximum.	Minimum.
January	71.0	42.3	64.2	45.1	66.3	36.9	67.5	35.3
February	75.2	43.9	67.6	46.8	72.3	41.2	70.3	37.9
March	83.5	50.0	73.0	50.4	78.4	48.9	76.9	43.5
April	93.4	60 6	82.6	59.0	85.7	55.1	84.5	48.1
May	101.7	66.2	90.7	63.7	91.3	60.3	93.0	52.4
June	104.0	72.1	93.6	67.3	101.8	68.1	103.1	60.5
July	104.0	73.4	95.5	69.6	104.1	75.8	104.2	72.2
August	103.1	73.0	93.9	70.2	104.8	74.2	102.3	72.7
September	99.1	69.8	89.6	67.3	99.5	67.1	99.6	63.3
October	93.0	62 6	84.6	64.4	89.5	55.5	87.1	50.2
November	84.0	54.7	75.7	56.3	78.6	44.6	75.4	39.5
December	74.1	44.6	67.5	48.4	68.3	36.5	64.8	34.1
Average for the year	90.5	59.4	81.5	59.0	86.7	55.4	85.7	50.8
Annual mean	74.9		70.2		71.0		68.2	

Saidy palms at Mecca must make up in the extra heat of July and August for the heat units in which Dakhla has been ahead from March to June. That they actually do this is proved by the fact that the Saidy trees at Mecca ripen their fruit a little earlier, if anything, than those at Dakhla.

The Tempe mean curve has the same form as that for Mecca and is nearly parallel with it, but after January it is about 3° F. lower throughout the year. From the relation of this curve to that of Heluan we should expect the Saidy to ripen at Tempe, for it shows Tempe to be the warmer station by from 3° to 6° F. through June, July, August, and September. It is only the analysis of the maximum and minimum temperatures of these stations that shows where Tempe fails.

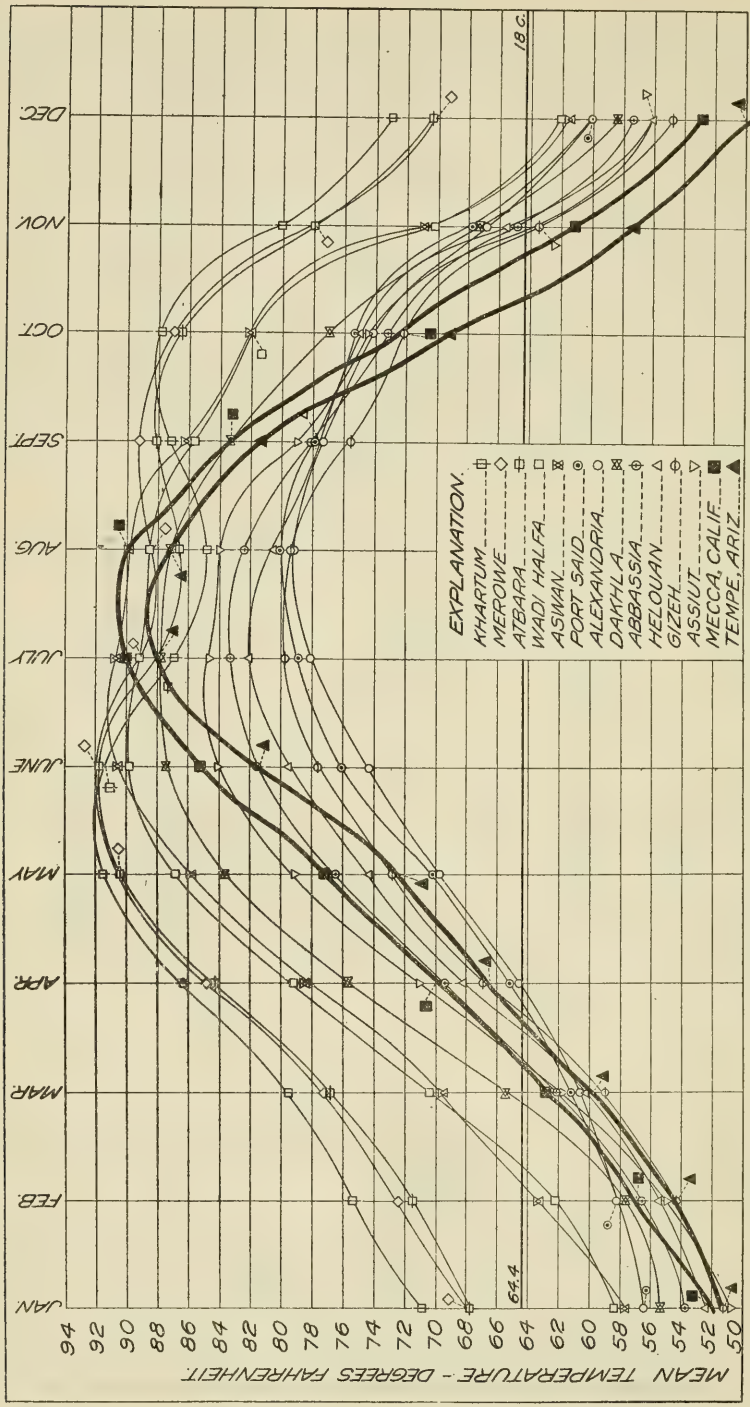


FIG. 4.—Curves showing the mean monthly temperatures in relation to the assumed "zero point" (64.4° F.) of the flowering of the date palm for 12 localities in Egypt and the Sudan, as compared with two localities (Mecca and Tempe) in the United States.

Comparing first the Dakhla Oasis with the Mecca garden in California, both points having an excess of heat above the requirements of the Saidy date, we may note that Dakhla has higher annual means (both maximum and minimum) by 3.5° or 4° F. than Mecca, but the Dakhla curves are broader ones, showing much higher maxima for March, April, and May, nearly the same as Tempe and Mecca from June to September, but with Mecca about 3° F. hotter in August. The Mecca minima are above those of Dakhla for both July and August.

Now, from the deductions relative to the temperature of Baharia made in a previous paragraph we must presume that the temperatures at Mecca more closely approximate those of Baharia than those of Dakhla. What Table 1 does not show is the occurrence of actual frost temperatures in Dakhla, but, quoting from the same authority, absolute minima of 0° C. were recorded in both January and February between 1905 and 1911, though the writer has been assured that nothing more than light frosts are ever experienced there.

At Mecca, on the other hand, there is an average of 20 frosty nights in the year, and the lowest annual minima of the record for 10 years range from 13° to 26° F. Fortunately, these extreme minimum temperatures endure for only a short period, usually not exceeding 30 minutes, as shown by the thermograph trace, and the frost never penetrates the growing center, though at 13° to 17° F. most of the outer leaves were killed.

Comparing the Dakhla records with those of Heluan, the mean maxima at Heluan are found to be from 6° to 11° F. lower throughout the year, the greatest difference being for the month of May. The mean minima for the year are nearly the same for Dakhla and Heluan, but the curves cross about March 15 and September 15—that is, Heluan has warmer nights in autumn, winter, and spring, but the nights are cooler than at Dakhla from the middle of March to the middle of September. Heluan is practically frostless, though Gizeh shows minima in January as low as —2.5° C., or 27.5° F. The harvest in the Nile Valley is prolonged to about two weeks later than in Dakhla. Frost would not interfere with the Nile Valley harvest before the new year, but the relative humidity at Heluan, always higher than at Dakhla, advances to 58 per cent in September and October and 62 per cent in November, while at Gizeh the humidity reaches 72 per cent in September and 75 per cent in October. It is evident that this upper Gizeh district has little heat to spare for the ripening of a choice packing date, and it is probable that it is practical cultural experience that has confined the field of culture of this date to the territory from Gizeh southward.

Our next inquiry should be, why this date, whether derived from the Libyan Oasis or from Gizeh, has failed to mature fruit at the Tempe garden. The annual mean maximum for Tempe is 85.7° F., only 1° below that of Mecca, where both the Libyan and Gizeh Saidy strains have ripened perfectly, some years early in September. The Tempe maximum curve is above the Heluan curve throughout the year, except for falling slightly below in November and December. It is far above it, practically with Dakhla, during June, July, August, and September.

It is to the Tempe minimum curve that we must look for an explanation of the failure to mature fruit of this variety. This curve falls

below all the others, only passing Heluan in July and August. There is a wide zone between it and the minimum curve of Mecca from flowering time to midsummer, falling below it by 7° and 8° F. even when the Tempe maximum passes that of Mecca, as it does in May and June. Heluan, with its moderate mean maximum of only 81.5° F., against 86.7° F. for Mecca and 85.7° F. for Tempe, has as a compensation a mean minimum for the year 8° higher than that of Tempe, 14° higher for the month of October, and nearly 17° higher for November.

Added to the cold nights, the Tempe garden has another handicap. The water table is at all times within 3 to 4 feet of the surface, so that the palm roots are in a constantly saturated subsoil, and no irrigation has been needed since 1907, when the present canal system of the valley was inaugurated. The sinking of the surplus water from irrigation at higher levels has created an underflow which has waterlogged many acres of land in the vicinity of this garden. Surface evaporation brings up so much alkali, chiefly sodium chlorid, that scarcely any weeds grow in the garden, a condition detrimental to fruit ripening. While the night temperatures are generally low in the Salt River Valley, it is believed that in localities having a warm sandy loam with good drainage and relatively free from alkali the Saidy date might ripen to a point where it would process into a fine product, with sufficient sugar concentration to make it keep without fermentation.[16]

RESISTANCE OF THE SAIDY DATE TO HUMIDITY AND DEW-POINT CONDITIONS.

A further comparison between the Saidy date and the Deglet Noor lies in its relative resistance to atmospheric humidity. In Deglet Noor plantations at the Tempe date garden and at Heber, Calif., when cool nights have developed a dew point during the latter part of August or early September, the fully grown but only partly matured fruits have developed spots of brown-rot, of some undetermined species, especially around the stalk, and dropped from the trees in large quantities. With a change to drier air this would sometimes cease at Heber and the rest of the crop mature.

The Saidy trees at the Tempe garden have not been known to suffer from these dew-point conditions.

In Gizeh Province the relative humidity is much higher than at either Tempe or Mecca. At Gizeh the average percentage is: August, 68; September, 72; October, 75. There is present on the leaves of the date palm growing in warm, humid stations, such as the lower coast regions of California and the southern Gulf Coast, a fungus of the group of smut fungi, *Graphiola phoenicis*. This, with other species, may be found on palms cultivated in greenhouses and conservatories, but seldom, if ever, occurs in the drier, more desertlike stations where the date palm usually is grown. It is a valuable humidity index, though seldom a serious detriment to date-palm growth.

[16] This present year, 1922, under conditions of an exceptionally dry summer in the Salt River Valley, some dates on the Saidy trees in the Tempe garden are ripening, thus increasing the probability that this variety may be matured in the drier and warmer localities of that section.

This fungus was observed by the writer on the leaves of the Saidy and other varieties of the date in gardens in the section near Bedrashen in upper Gizeh, where the Saidy fruits heavily and is matured and packed in great quantities. Through the kindness of Thomas W. Brown, director of the horticultural section of the Ministry of Agriculture at Gizeh, the following communication was procured from the director of the meteorological service of the ministry of public works, physical department, under date of March 21, 1921:

> Our records show that at Gizeh on an average the temperature falls below the dew point on 20 days in each of the months September and October, causing fog at some time of the early morning. We have no records for the Hawamdia district itself, and though it is not likely to be very different from Gizeh, I think that the fogs would be of rather less frequent occurrence there.

The evidence of these Egyptian weather records, confirmed by the presence of this fungus, is that the Saidy date will mature without loss with the relative humidity of the ripening months at from 68 to 75 per cent and with the frequent occurrence of dew point and fog. From this we may safely conclude that the occasional dew points of the Imperial Valley in California during the ripening season need not be feared for this variety. This information is of the highest importance, for it opens up to the culture of the Saidy date a vast area in the Imperial Valley of California and in the lower Colorado Valley of both California and Arizona, where the culture of the Deglet Noor has proved hazardous on account of dew-point conditions during the ripening season.

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UNITED STATES DEPARTMENT OF AGRICULTURE
BULLETIN No. 1105

Washington, D. C. ▼ April 27, 1923

NATURAL REPRODUCTION OF WESTERN YELLOW PINE IN THE SOUTHWEST

By

G. A. PEARSON, Silviculturist
Fort Valley Forest Experiment Station
Forest Service

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UNITED STATES DEPARTMENT OF AGRICULTURE
BULLETIN No. 1106

Washington, D. C. ▼ October 23, 1922

LEGAL PHASES OF COOPERATIVE ASSOCIATIONS

By

L. S. HULBERT, Assistant in Cooperative Marketing
Bureau of Agricultural Economics

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UNITED STATES DEPARTMENT OF AGRICULTURE
BULLETIN No. 1107

Washington, D. C. PROFESSIONAL PAPER December 4, 1922

THE LEAD-CABLE BORER OR "SHORT-CIRCUIT BEETLE" IN CALIFORNIA

By

H. E. BURKE, Entomologist, R. D. HARTMAN, Field Superintendent in Insect Control, and T. E. SNYDER, Entomologist, Forest Insect Investigations, Bureau of Entomology

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UNITED STATES DEPARTMENT OF AGRICULTURE
BULLETIN No. 1111

Washington, D. C. ▼ November 25, 1922

ONE-VARIETY COTTON COMMUNITIES

By

O. F. COOK, Bionomist in Charge of the Office of Crop Acclimatization and Adaptation Investigations
Bureau of Plant Industry

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1922

UNITED STATES DEPARTMENT OF AGRICULTURE
BULLETIN No. 1112

Washington, D. C. ▼ December 21, 1922

THE WESTERN YELLOW PINE MISTLETOE

EFFECT ON GROWTH AND SUGGESTIONS FOR CONTROL

By

CLARENCE F. KORSTIAN, Forest Examiner, Appalachian Forest Experiment Station, Forest Service, and W. H. LONG, Forest Pathologist, Office of Investigations in Forest Pathology, Bureau of Plant Industry

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UNITED STATES DEPARTMENT OF AGRICULTURE

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CITRUS SCAB: ITS CAUSE AND CONTROL

By

JOHN R. WINSTON, Pathologist
Office of Fruit-Disease Investigations, Bureau of Plant Industry

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LUMBER CUT OF THE UNITED STATES 1870-1920

DECLINING PRODUCTION AND HIGH PRICES AS RELATED TO FOREST EXHAUSTION

BY

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THE EFFECTS OF INBREEDING AND CROSSBREEDING ON GUINEA PIGS

III. CROSSES BETWEEN HIGHLY INBRED FAMILIES

By SEWALL WRIGHT
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